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THE MERCURY VAPOUR LAMP HP 300

Contents. Electrical discharges through mercury vapour at high vapour pressures constitute light-sources with a high luminous efficiency coupled with small overall dimensions. The new mercury vapour lamp "Philora" HP 300, which is designed for connection to alternating current mains, has roughly the same size and shape as an incandescent lamp of the same rating (75 watts) but gives three times the luminous flux. The present article discusses the electrical and illumination characteristics of this lamp, with special reference to the importance and the function of the current-limiting unit (series or leak transformer) and the spectral composition of the emitted radiation.

Introduction

In the history of the technical application of electricity for illumination purposes various periods of development can be distinguished. Neglecting consideration of the arc lamps, the first period may be regarded as starting from the time Edison demonstrated his first carbon-filament lamps and lasting to the beginning of the present century, during which these carbon filament lamps completely held the field. About 1900 there appeared the first Nernst lamps and a variety of metal-filament lamps, first merely as negligible competitors, but later gaining such ground that by about 1912 they had practically ousted the carbon-filament lamp. And today when the field has been held almost exclusively by the tungsten-filament lamp for a period of nearly 25 years, gas-discharge lamps are steadily encroaching on its preserves. In a variety of important directions sodium and mercury lamps have already been adopted on a large scale for practical purposes, principally for street and road lighting and for illuminating shunting-yards and workshops.

In the new "Philora" lamp HP 300 Philips have added a small mercury-vapour lamp, which possesses an exceptionally high efficiency, the output of light being about three times that of a tungsten lamp of the same rating. In the long run, will this lamp be capable of displacing the tungsten lamp in the same way as the latter has completely superseded the carbon-filament lamp?

No, this cannot be anticipated, since the tungsten lamp possesses certain desirable characteristics which are lacking in the new lamp. Thus the tungsten lamp burns at its full brilliancy the moment it is switched on, whilst in the new lamp several minutes must elapse before this state is reached. Moreover, the colour of the mercury light differs from that which one has become accustomed to with the incandescent lamp.

But what may be expected from the new lamp? Wherever the level of illumination is low, a marked increase in this level can be obtained with a lamp of this type for a small extra current consumption. By mixing the mercury light with that of the incandescent lamp a very pleasing tone coupled with a high luminous efficiency is obtained. Thus if tungsten lamps of 200 watts are supplemented by a 75-watt mercury lamp, the luminous flux is practically doubled, and all colours appear very nearly the same as in ordinary daylight. This mixed light thus offers advantages as compared with the light obtained from each source separately.

Although the carbon-filament lamp during the early years of lighting by electricity made a very important contribution to the development of this branch of electrical engineering, it yet remained to the much more efficient tungsten lamp to popularise the use of electric lighting to a degree which a decade previously no one would have dared to prophecy. In less than 50 years the annual consumption of incandescent lamps has grown to more than a thousand million, accounting for the consumption of about 25 10^9 kWh of electricity per annum. Electric lighting has introduced electricity into practically every household.

We are now again on the threshold of an important advance in the increased efficiency of electric lighting. In view of the fact that the level of illumination in practically all applications of electric lighting still is kept very low for economic reasons, it appears that the new lamp will also open up a number of new avenues of application for electric illumination which have hitherto not been accessible to it.

Characteristics of the New Mercury Lamp

Fig. 1 shows the mercury vapour lamp in its natural size. The discharge tube is of quartz, with the liquid mercury contained in the small cupules which surround the electrodes. During operation the pressure of the mercury vapour rises to 20 atmos. The external dimensions of the glass bulb are similar to those of an incandescent lamp of the same rating. The principal electrical and illumination data for this lamp are collected in *table I*.

TABLE I. Characteristics of the mercury lamp HP 300 in stationary operation.

Voltage-drop across the lamp	230 volts
Current intensity	0.4 amp
Consumption of lamp	75 watts
Losses in connected transformer 5450 G/86	15 watts
Power factor	0.55
Luminous flux	3000 lumens
Net yield of light	33 lumens per watt
Diameter of discharge tube	ab. 4 mm
Distance between electrodes	18 mm
Mean luminous density	420 candles/sq. cm
Luminous density along axis	ab. 1150 candles/sq. cm

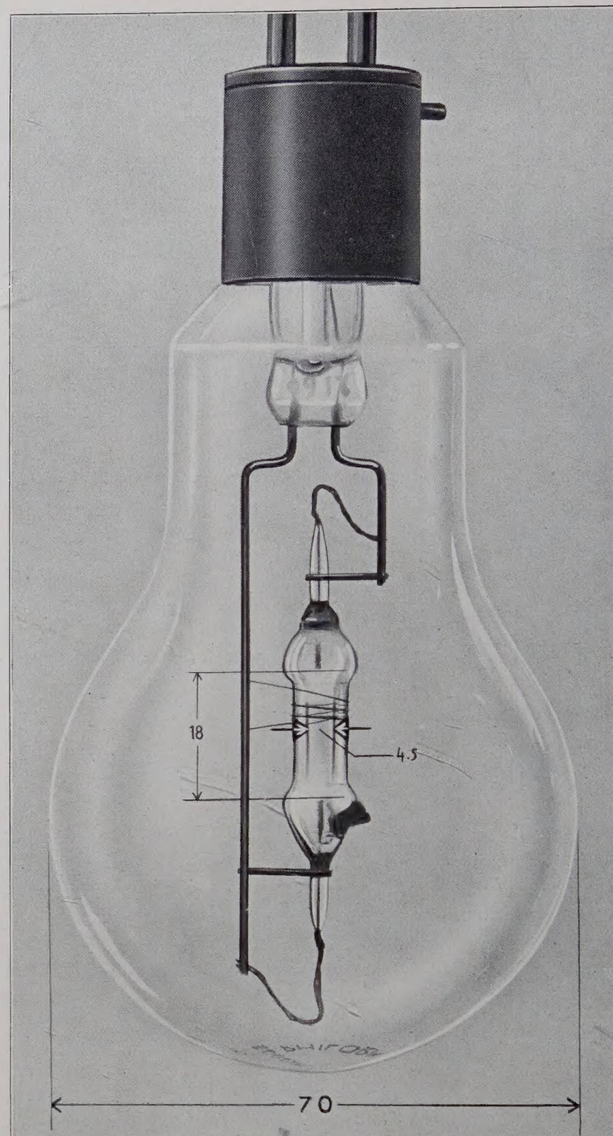

Fig. 1. Mercury vapour lamp "Philora" HP 300 rated for 75 watts and 3000 lumens in natural size.

The lamp is designed for running from an alternating-current mains supply. As with all other gas-discharge lamps, the new mercury vapour lamp also may not be connected directly to the mains, but must be connected in series with a resistance, condenser or a self-induction coil, in order to limit the current. The use of resistances is naturally avoided as far as possible in order to guard against supplementary power-losses. A strikingly simple solution of this problem is offered by the use of a transformer with a high leakage which serves both as a voltage source and as an inductive series resistance. The leak transformer (type No. 5450 G/86) provided for the new lamp is so rated that on the secondary side an inductive resistance of suitable magnitude is obtained and on connecting to a 220-volt mains supply the open-circuit voltage of 410 volts(eff.) for starting up and running the lamp is furnished.

To obtain a closer insight into the operation of this current-limiting unit, oscillograms were registered of the voltage drop U_E across the discharge and U_L across the unit in question, as well as of the total voltage U and the current intensity I (*fig. 2*). These curves show that the total tension is practically of sinusoidal form. On the other hand the voltage-drop U_E at the discharge when represented as a function of the time is roughly of rectangular form. The magnitude of the voltage-drop is thus almost independent of the current intensity, and we will call it the running voltage E_B. The direction of the voltage-drop, however, suddenly reverses when the direction of the current is reserved. The instant after reversal the voltage-drop rises to a higher value E_D, which we will term the re-ignition voltage, as this voltage is necessary to re-ignite the lamp when it becomes extinguished each time after reversing the current. The voltage U_L at the series transformer is equal

to the difference between U and U_E. It is therefore not sinusoidal but, as shown in the figure, has a

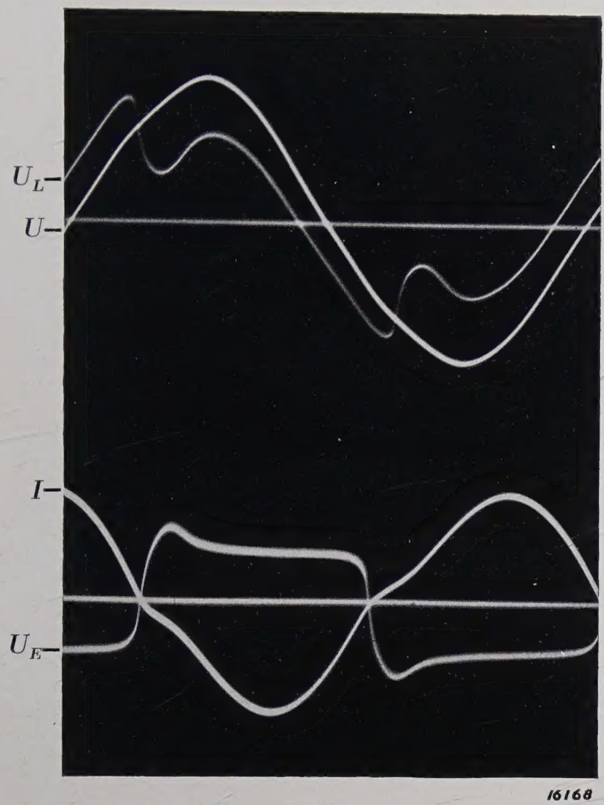

Fig. 2. Oscillograms of mercury vapour lamp HP 300 under normal running conditions. U_E = discharge voltage; U_L = voltage at series unit; U = total voltage; I = current intensity.

fairly complex form. As the series transformer has an inductive resistance, the following relationship holds between the current intensity I and the voltage U_L:

$$U_L = L\frac{dI}{dt}.$$

This expression indicates in accordance with fig. 2 that the current attains its highest value when the voltage U_L changes sign. Only when this has occurred does the current commence to drop. It is thus found that the current lags behind the feed voltage U, which was to be expected owing to the inductive character of the series transformer, although the currents in question here are not sinusoidal. When the current intensity becomes equal to zero, the voltage-source is already furnishing an appreciable reverse voltage. The magnitude of the re-ignition voltage E_D now determines whether this reverse voltage is sufficient to re-ignite the lamp immediately in the opposite direction after it has been extinguished. This is definitely possible if the ignition voltage is sufficiently low, as in the case shown in fig. 2. But under certain working conditions the lamp remains dead for a finite period, the so-called dark pause, before the current changes direction and before the tension has again reached such a value that re-ignition of the discharge takes place. *Fig. 3* shows the calculated fluctuation of the voltages and the current intensity assuming a sinusoidal total voltage, a rectilinear voltage-drop at the lamp and a purely inductive resistance at the series transformer. The agreement with the oscillograms is very satisfactory.

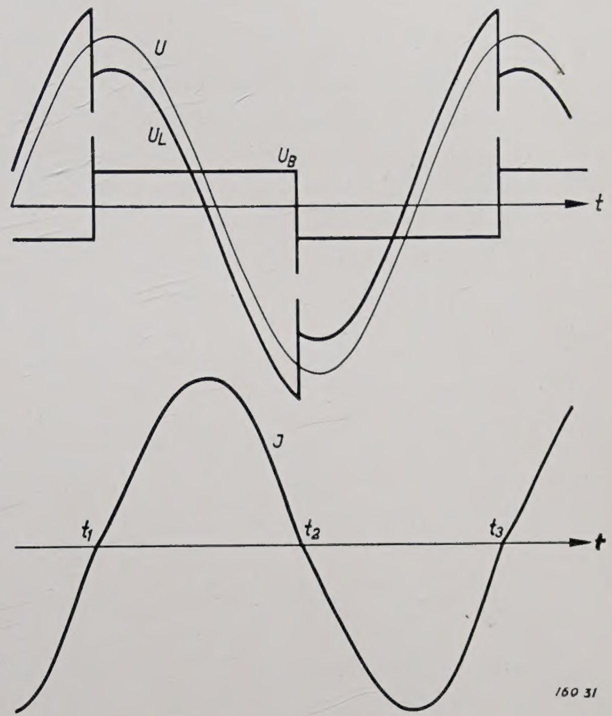

Fig. 3. Calculated current and voltages of the gas discharge and the series unit assuming simplified characteristics for the lamp. The concordance with the oscillograms is very satisfactory.

Shortness of the dark pause is not only advantageous from considerations of better illumination (less flickering) but also enables the lamp to be run with the minimum feed voltages. The re-ignition voltage E_D is indeed not constant but increases during the dark pause, and as a result the running of a lamp with a resistance in series requires higher peak voltages than when using chokes in series.

Heating-up and Stability

The voltage-drop E_B and the power output W of the mercury-vapour discharge both increase with the vapour pressure. If W is represented as a function of E_B, nearly a straight line as shown in *fig. 4* is obtained for the HP 300 mercury lamp. The curves N_1, N_2 and N_3 give the inputs of the lamp fed through the series unit, also as a function of the voltage drop, for an opencircuit voltage U

of 410 volts$_{eff}$ and various settings of the leak transformer. Expressed as a function of the voltage-drop the power input has a maximum value. This may be readily understood, for at $E_B = 0$ the voltage-drop disappears and at $E_B = 580$ the current disappears. Actually the curve already breaks off at $E_B = 350$ volts, as the re-ignition voltage then exceeds the maximum open circuit voltage (580 V).

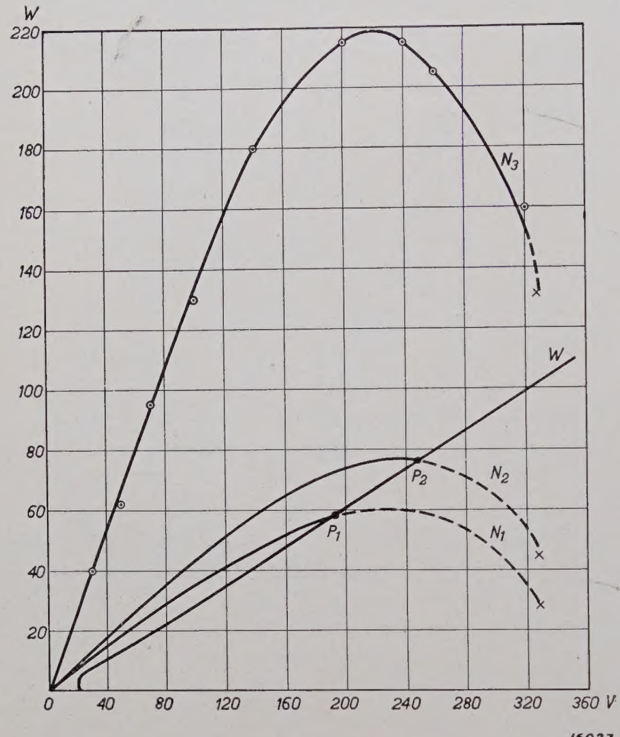

Fig. 4. The power output W of the mercury lamp HP 300 plotted as a function of the voltage-drop E_B under normal cooling conditions. The curves N_1, N_2 and N_3 show the inputs of the lamp with a total voltage of 410 volts$_{eff}$ and various settings of the leak transformer. The points P_1 and P_2 correspond to stable working states of the lamp. If the energy input is that corresponding to the top curve N_3 no stable working point is obtained. The lamp becomes heated and goes out as soon as the re-ignition voltage rises above the maximum voltage applied to the lamp.

On switching on the cold lamp, the input power N is initially greater than the total output W. As a result the lamp heats up, whereupon its voltage-drop E_B, and hence also the power output W according to fig. 4 increases. The input power expressed as a function of E_B is represented by the curve N_2 for a load slightly higher than normal. In this case the heating-up stage terminates at $E_B = 250$ volts in the stationary working state P_2, in which the energy input N_2 and the radiation emitted W are equal.

Consider now the heating-stage curve N_3 which was obtained with a lamp running on a heavy overload. The output in this case too follows the curve W. As the input of energy is always in excess, the temperature as well as the re-ignition voltage rises until (at $E_B = 350$ volts) the maximum feed voltage is insufficient to ignite the lamp. The discharge is then extinguished, the temperature drops, the lamp is re-ignited after the elapse of a short interval and so on.

When the lamp is running on a subnormal load (heating-stage curve N_1) no abnormal behaviour is observed. The difference between the heat input N_1 and the output W is, however, very small as shown in the diagram, so that the time taken to reach the stationary state on reducing the power input increases very considerably. Moreover, owing to the small angle between the curves N_1 and W the position of the working point P_1 (stationary state) is very susceptible to slight displacement of these curves, i.e. small changes in the working conditions.

Under certain operating conditions (intense cooling and subnormal load), it may even happen that a lamp will not become heated to the normal working state. Such a case is shown in *fig. 5*. The stationary working point is P with a voltage E_B,

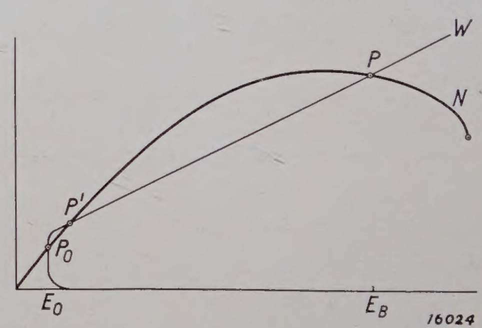

Fig. 5. The same as fig. 4, but with abnormally high cooling and insufficient energy input (diagrammatic). The stable working point P is not attained, as the input N and the output W are already in equilibrium at the point P_o.

but this working level is not attained. During heating, the lamp does not get beyond the first point of intersection P_o of the curves N and W, so that at the very low running voltage E_o it remains at the stage corresponding to a low-pressure discharge. To get it into a proper working condition, the vapour pressure must be raised by suitable means, e.g. by external heating, to such a level that the running voltage rises above the second point of intersection P' of the curves W and N. In this case the input energy will again exceed the output energy, so that the lamp will continue to heat itself and tend to attain its stable end state.

It can thus be generally concluded that the normal load of the lamp is fixed within certain

limits. With a subnormal load the temperature rises too slowly, whilst with a very heavy overload no stable working point is obtained. The mean heating curve is obtained when using the leak transformer 5450 G/86 for an output of 75 watts in the end state. The curves in *fig. 6* show the heating process as a function of the time.

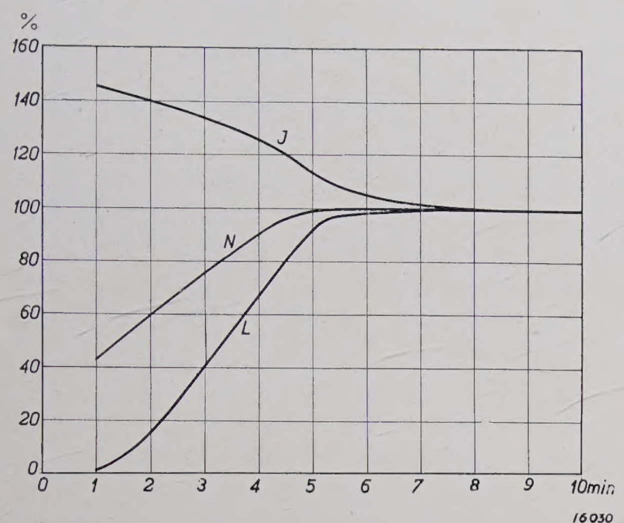

Fig. 6. Current intensity *I*, power *N* and luminous flux *L* of the mercury lamp HP 300 expressed in percentages of their end values and plotted as a function of the time after switching on. After the elapse of about 5 minutes the lamp gives about 90 per cent of its total luminous flux.

Illumination Characteristics

The luminous flux of the new mercury vapour lamp on a normal load is 3000 lumens. As the current-limiting unit itself absorbs about 15 watts, the light yield is 33 lumens per watt [1]). The spatial distribution of the light emitted by a lamp suspended vertically and with an opal globe is shown in *fig. 7*. A detailed discussion of the spectrum of the mercury-vapour discharge has already been published in a previous issue of Philips techn. Rev. (**1**, 5, 1936), where it was indicated that the distribution of spectral intensity was determined by the vapour pressure of the mercury. In general it may be assumed that the higher the vapour pressure the richer will be the spectrum in long-wave (red and infra-red) radiation, and hence the stronger will the ultra-violet lines be absorbed by the vapour. In addition the lines are broadened to an increasing extent and a continuous background appears between the lines especially in the visible region. *Fig. 8* shows the intensity distribution of the new mercury-vapour lamp in the visible spectrum. The figures at the peaks of the curves indicate the percentage contribution of the corresponding lines to the total luminous flux. As could be expected, this lamp already has a definite continuous background as well as an appreciable proportion of red light. Nevertheless the spectral distribution still deviates very considerably from that of daylight and the light given by incandescent lamps.

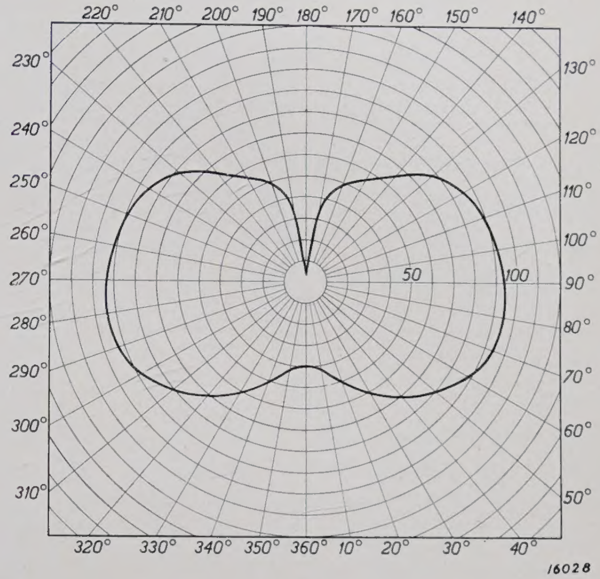

Fig. 7. Spatial distribution of the luminous flux of the new mercury lamp with opal globe.

To obtain a convenient survey of the spectral distribution the scale of wave-lengths has been subdivided in *table II* into four ranges, these

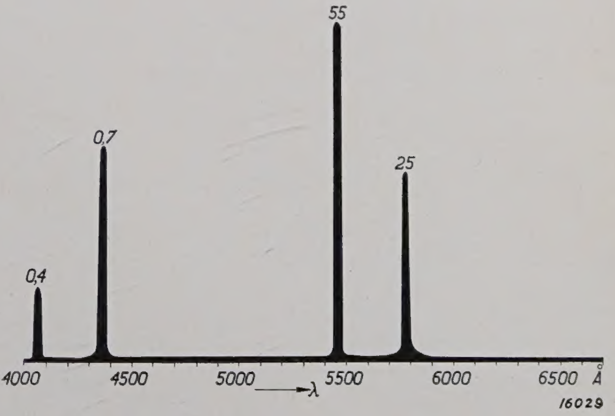

Fig. 8. Intensity distribution of the radiation of the new mercury lamp in the visible spectrum. The figures at the peaks of the intensity curve represent the percentage contribution of the respective spectral lines to the total luminous flux.

ranges being of such extent that they contribute equal proportions of luminous flux in the case of a spectrum of constant intensity in the wave-length scale (so-called equal energy spectrum). As indicated by table II, solar radiation is distributed almost uniformly over the different ranges selected. The

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[1]) With the same power, the efficiency of an incandescent lamp is approximately 13 lumens/watt.

TABLE II. Distribution of luminous flux of various light-sources over four spectral ranges of visible light expressed as a percentage of the total light output.

Range of wave-lengths Å	Equal energy spectrum	Sun	In-cand. lamp	Mercury vapour lamp HP 300	Mixed light. G and H denote the luminous flux of the incand. lamp and the mercury vapour lamp resp.	
					$G/H = 1/1$	$G/H = 2/1$
	%	%	%	%	%	%
4000—5300	25	26	14	8	10	12
5300—5580	25	26	22	58	40	34
5580—5880	25	25	28	31	30	29
5880—7000	25	23	36	3	20	25

incandescent lamp contains a higher proportion of long-wave radiation and a less proportion of short-wave. The mercury-vapour discharge is made up mainly of yellow and green light. The blue lines, owing to their very short wave-length (4358 Å and 4047 Å), contribute only very little to the total luminous flux. Although long-wave radiation ($\lambda =$ above 5880 Å) is indeed present as a continuous background it is by no means sufficient to produce a natural impression.

Control of the Spectral Composition of the Light

Experiments have shown that the impression given by coloured surfaces on illumination with mercury vapour lamps can be considerably improved by the admixture of red radiation. This may be done in various ways, e.g. the use of red-fluorescing reflectors or the addition of light from incandescent lamps, which as we have seen has an excess of red radiation as compared with daylight. In order to give a numerical instance of the degree of adaptation, two cases of mixed illumination are included in Table II. Favourable adaptation appears to be obtained when about $^2/_3$ of the light is furnished by incandescent lamps and $^1/_3$ by the mercury vapour lamp. In this case the proportions of yellow and red radiation compare favourably with those of sunlight, although there is an excess of green and a corresponding lack of blue radiation. Perfect adaptation to the spectral intensity distribution of sunlight can naturally not be achieved and is possibly not desirable at all. It is indeed, quite probable that the eye requires a different distribution of spectral intensity with artificial light than with daylight owing to the necessarily lower brightness. The best mixture of glowlamplight and mercury vapour light can therefore only be determined by experiment.

Compiled by G. HELLER.

THE SOUND RECORDER OF THE PHILIPS-MILLER SYSTEM

by A. TH. VAN URK.

Summary. In this article the connection between the resonance frequency and the attainable amplitude is discussed for various constructions. It is shown that the attainable amplitudes are very small in all cases (of the order of 0.1 mm) and only by a marked magnification of the amplitude by means of the special shape of the cutter can a sound track of normal width (1,8 mm) be recorded. The magnetic driving system finally evolved and its operating characteristics are discussed in detail.

In the previous issue of this Review the basic principle of the Philips-Miller system of sound recording was described and a comparison made with those methods in use hitherto [1]). Attention was called to certain difficulties which had to be overcome at the outset in developing the new method. In particular it was indicated that the construction of the apparatus for recording sound by mechanical means, i.e. the sound recorder, constituted the nucleus of the method.

The fundamental principle of the method is as follows. Under a stylus or cutter S a tape is displaced which is composed of a celluloid base C covered with a simple transparent layer of gelatine G which is itself coated with a very thin opaque coating D (*fig. 1*). The cutter is a wide-angled wedge as shown in fig. 1. On its displacement in response to the sound vibrations, this cutter moves in a direction perpendicular to the tape and cuts a strip of varying width out of the top coating of the film, thus giving a transparent sound-track on an opaque background. The sound-track, produced mechanically in this way is used for sound reproduction by optical means.

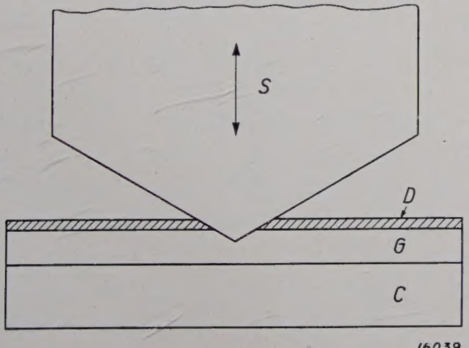

Fig. 1. Principle of the Philips-Miller system. S = Wedge-shaped cutter. C = Celluloid base G = Transparent gelatine surface. D = Opaque coating of "Philimil" strip on which the sound-track is produced.

It was pointed out earlier that by combining mechanical recording with optical reproduction a number of important advantages are obtained. The method had, however, one difficulty, viz, that in order to produce an equivalent sound amplitude, the amplitude to be recorded must be much greater at high frequencies than in older systems of mechanical recording (gramophone discs). The mechanical vibrating system, composed of the driving system of the cutter, must have a very high resonance frequency in order to obtain an amplitude independent of the frequency in the frequency range embracing musical sounds [2]).

This condition cannot be combined with a large amplitude [3]). By the wedgeshaped form with the obtuse angle of about 174° of the cutter adopted by Miller and the magnification of 40 obtained thereby, it has been possible to work with a cutter amplitude of 25 μ. Yet even this apparently minute amplitude is just at the practical limit — at the high resonance frequency in question [4]).

Amplitude and Natural Frequency of the Sound Recorder

If the sound recorder is designed with a high natural frequency the vibrating system becomes comparatively insensitive; it responds only with small amplitudes and powerful driving forces must be provided in order to obtain an adequate amplitude. The actual increase in these forces is however limited by the permissible stresses which

1) R. Vermeulen: The Philips-Miller System of Sound Recording, Philips techn. Rev. 1, 107, 1936.

2) Philips techn. Rev. 1, 107-114, 1936. See here equation (1) and fig. 10 on p. 112.

3) The maximum amplitude of the sound track has been standardised to 1·8 mm. (Here and elsewhere in the computations 2 mm are adopted for the reason of simplicity).

4) For comparison it may be mentioned that the diaphragm of a powerful loudspeaker oscillates with an amplitude of some tenths of a μ at the highest frequencies.

can be applied to the material. It is important to note that this limit is independent of the dimensions of the sound recorder and is determined solely by the mechanical properties of the material. This may readily be seen from a simple example, as shown below:

Consider the case of a rod of circular section which is firmly secured at one end (*fig. 2*). The

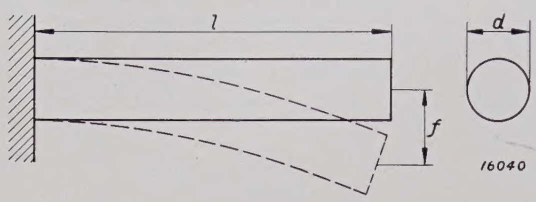

Fig. 2. Bar of circular section clamped at one end to form a simple mechanical oscillating system. Length of bar l, sectional diameter d, flexure f.

minimum natural frequency n of the transverse vibrations is:

$$n = 0.140\ d\ c/l^2, \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where d and l are the dimensions of the rod as shown in fig. 2 and c is the velocity of sound through the material of the rod. On the other hand the amplitude f of the end of the rod with an oscillation corresponding to the lowest natural frequency is:

$$f = {}^2/_3 \cdot \frac{\sigma_{max}}{E} \cdot \frac{l^2}{d}, \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where E is the modulus of elasticity and σ_{max} the maximum stress in the rod. Multiplying these two equations together, we get

$$nf = 0{,}0935\ \sigma_{max}\ c/E \quad . \quad . \quad . \quad . \quad (3)$$

The dimensions of the rod l and d are now no longer contained in this expression. The same result could also be deduced ror other types of vibrating systems. If we substitute in (3) the values for iron $c = 5.10^5$ cm. per sec and $E = 2.10^6$ kg per sq cm, and put $f = 25\mu$ and $\sigma_{max} = 1300$ kg per sq. cm (i.e. approx. the maximum stress), we get

$$n = 12000 \text{ cycles/sec}$$

We thus see that the limiting natural frequency calculated in this way is still sufficiently above the audio-frequencies.

Driving System

For a given natural frequency of the recorder, the attainable amplitude is limited not only by the proportionality limit of the material, but also by the forces available for driving the mechanical vibrating system. There are in the main two types of drive which can be employed, viz, the electrodynamic and the electromagnetic. In the electrodynamic drive a coil through which a fluctuating current I (in amperes) flows is situated in a constant magnetic field H (see *fig. 3*). A force $0.1{\cdot}H{\cdot}l{\cdot}I$ then acts on the coil, where l is the length

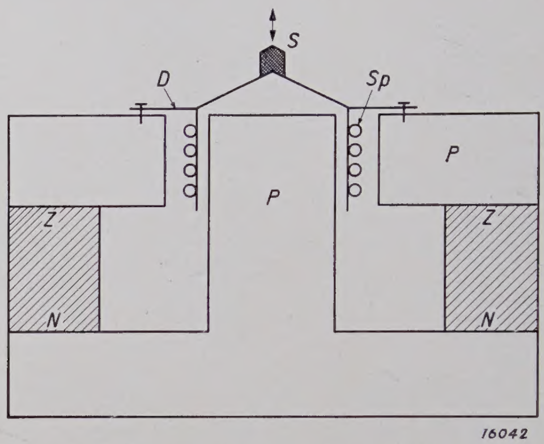

Fig. 3. Electrodynamic drive. Coil Sp, through which the microphone currents pass, moves between the pole-pieces P in the permanent magnetic field generated by the magnets ZN. The coil is represented as held in position by a flat spring D. The cutter must be attached at S, motion being in the direction of the double arrow.

of wire on the coil. If furthermore its mass is m and it is so fixed that the resonance frequency is $\omega/2\pi$, the amplitude of the coil will be:

$$a = \frac{0.1\ HlI}{m\ \omega^2} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Introducing the cross-sectional area q and the density ϱ of the coil wire, as well as the current density i, we can substitute $I = iq$ and $m = lq\varrho$ [5]), and thus obtain for the amplitude of the coil the expression:

$$a = 0.1\ \frac{H\,i}{\varrho\,\omega^2} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Again all dimensions of the system are absent in the result. To obtain a great amplitude at the given resonance frequency $\omega/2\pi$, H and i must be made large and ϱ made small. In practice the maximum values which can be obtained are: a field strength H of 15000 gauss, a maximum current density i of 10 A per sq.mm and a minimum density ϱ of 3 gr. per cub. cm. (alumnnium). With the very low resonance frequency of 3500 cycles ($\omega = 2\ \pi \cdot 3500$) one computes from (5) that the attainable amplitude is $a = 10\ \mu$, which is insufficient for a full modulation of the sound track. Further progress cannot be made in this direction as a limit is set by the properties of the material.

[5]) The small mass of the body of the coil has been neglected here.

For this reason the electromagnetic driving system has been preferred, as shown diagrammatically in *fig. 4.* Contrary to an electromagnetic system the attainable amplitude with the elec-

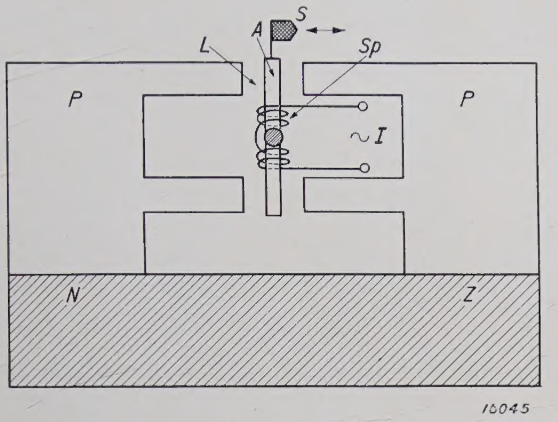

Fig. 4. Electromagnetic drive. The armature A which is energised by the coil Sp (microphone current I) moves in the air gap L between the pole-pieces P. The cutter is attached at S and moves in the direction of the double arrow.

tromagnetic system is determined by the dimensions of the system. The amplitude is found to be:

$$a = k \frac{H_o \, \Delta H}{\varrho \, \omega^2} \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where ΔH is the alternating field in the armature A and H_o the field in the air gap L due to the permanent magnet P; k is a factor of the dimension of a reciprocal length and is inversely proportional to the dimensions of the system. By reducing the size of the recorder its amplitude can be increased, although there is an upper limit to this increase due, inter alia, to the fact that the air gap L must remain appreciably larger than the amplitude a of the vibrating armature. At a resonance frequency of approx. 5000 cycles, an amplitude of about 30μ was cut with the driving system shown in *fig. 5.*

Description of the Sound Recorder

The interior of the sound recorder is shown diagrammatically in *fig. 6. Fig. 7* shows the armature component separately. The armature is connected with the two clamping plates ***Pl*** by a pair of short bridge stays T which provide a torsion axis. In designing the sound recorder, the first requirement to be met was that air gap (L in fig. 4), in which the armature moves, must be made large compared with the armature amplitude, as otherwise the dispacement of the armature would not be proportional to the force. On the other hand tbe air gap must be kept small in order that the magnetic resistance of the magnetic circuit does not become too large. The air gap is only 0.12 mm, accurate adjustment to this value being obtained in the following way. The armature is made in one piece with the clamping plates ***Pl*** and the torsion stays, and is ground quite flat. Similarly

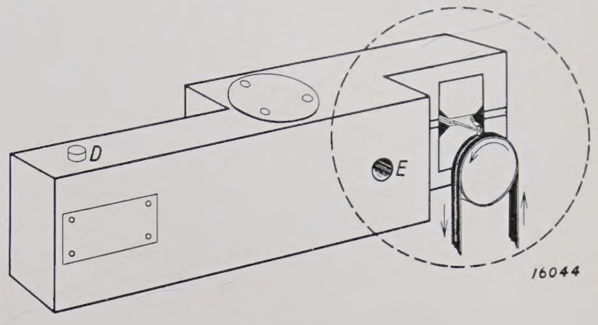

Fig. 5. Diagrammatic sketch of the sound recorder. To regulate the depth of the track in the film, the sound recorder can be turned about the axis E by means of the adjustable stop D. The part enclosed in the dotted circle is reproduced on an enlarged scale in fig. 6.

the upper pole-piece together with the top part of the brass frame R in which it is countersunk, and the lower pole-piece with the lower section of the frame are also ground flat on the front surfaces. When clamping the armature thin spacing sheets ***Zb*** (figs. 6), exactly 0.12 mm in thickness, are

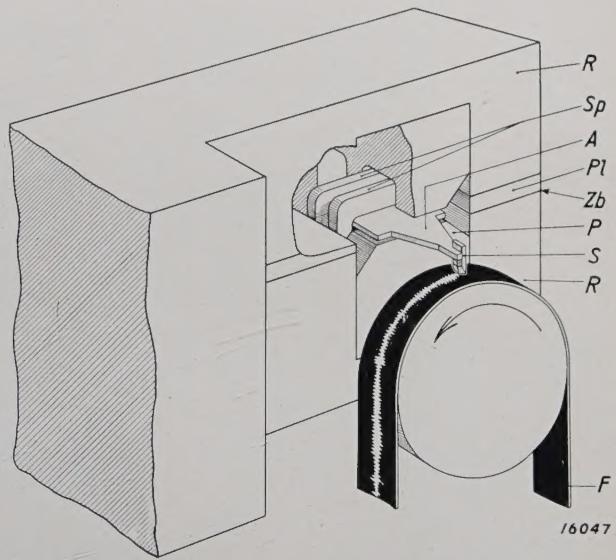

Fig. 6. View of the interior of the driving system, showing the pole-pieces P (Z = south pole, N = north pole) countersunk in the brass frame R, between which the armature A oscillates. The energising coils Sp enclose the armature A which is clamped between the upper and lower halves of the frame by means of the clamping plates Pl, the spacing plates Zb serving for accurately adjusting the required air gap between A and P. To a lug on the armature A is attached the cutter S which engraves the sound-track in the film F when the latter moves in the direction of the arrow.

inserted between the end surfaces of the frame and the clamping plates ***Pl.*** This arrangement gives the required dimension for the air gap between the pole-pieces and the armature. The

marked torsional rigidity of the short stays with which the armature is secured in position, provides the necessary powerful controlling force and hence the high resonance frequency of the armature vibrations frequently referred to above.

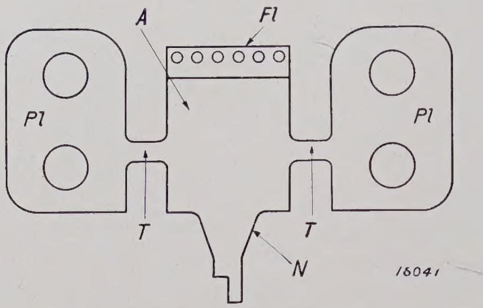

Fig. 7. The flat armature component consists of the armature proper A, the links T providing a torsion axis, and the clamping plates Pl. The armature is provided with a lug N for attaching the cutter and a vane Fl for providing additional damping, see page 141.

To obtain the high field-strengths H_0 and ΔH which are required here (equation (6)), provision must be made for a low magnetic resistance in the iron circuit, in addition to a small air gap. The pole-pieces have therefore been given a large section and are made of a nickel-iron alloy, a material with a high permeability and a high magnetic saturation. The electrical conductivity of this material is small so that eddy current and hysteresis losses are slight. In view of the limited mechanical strength of this alloy it was, however, not suitable for the armature. This is made of a silicon-iron (4 percent Si) having practically the same magnetic and electrical properties as the nickel-iron alloy; it is, however, very much harder and more brittle. The brittleness is here not a disturbing factor as the armature unit requires only very simple machining and finishing. In *fig. 8* the sound recorder is depicted, mounted on the desk of the recording machine.

Frequency Characteristics of the Sound Recorder

Determination of the frequency characteristic of the sound recorder in the no-load condition, i.e. without the cutter making a trace on the film, gives a resonance curve of the type shown in the family of resonance curves in fig. 10 on page 112 of the previous issue of this Review, which relate to a simple mechanical vibrating system. This characteristic is reproduced in *fig. 9*, curve A.

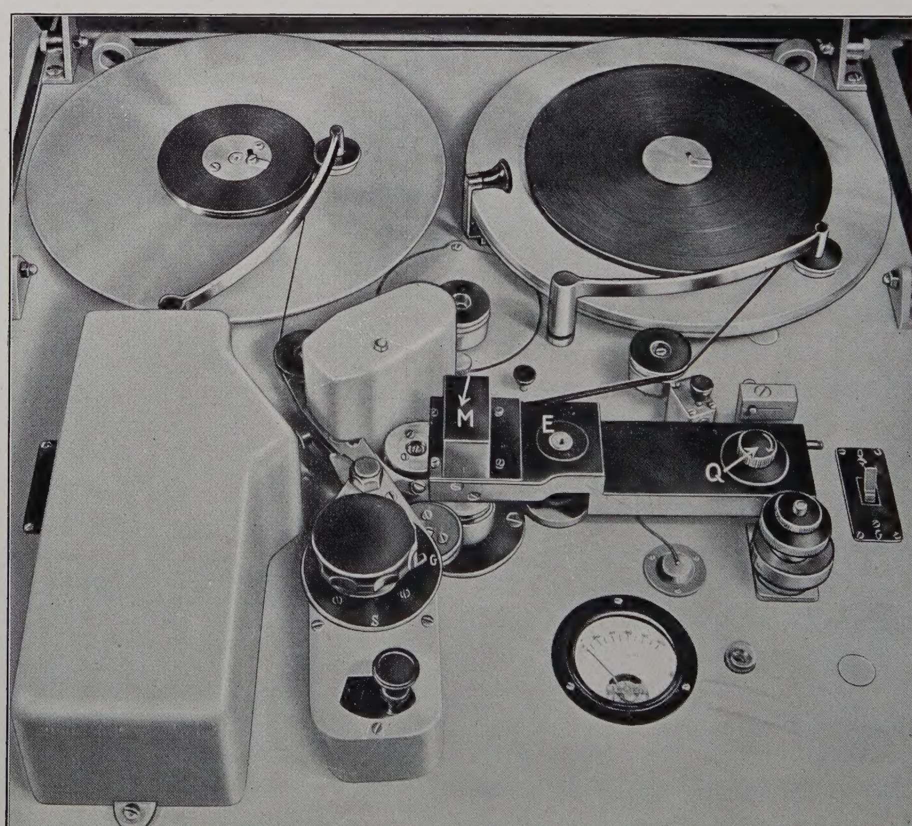

Fig. 8. The sound recorder mounted on the desk of the recording machine. By means of the micrometer screw Q which displaces a stop (not visible here, see D in fig. 5) the whole recording unit can be turned about the pin E for adjusting the depth of tracing of the cutter.

On graphing the corresponding characteristic for the sound recorder on load [6]), i.e. during the tracing of the sound-track, the shape and the absolute height of the resonance curve are found to be altered (fig. 9, curve B). The flattening of the resonance peak is due to the damping action exercised by the film on the vibratuon of the armature. At the same time there is also a lateral displacement in the position of the resonance maximum which is due to the fact that the film not only applies a damping force (which only absorbs energy) to the cutter, but as already men-

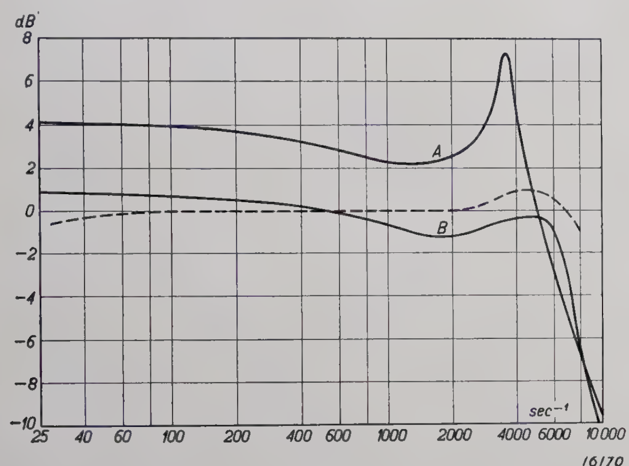

Fig. 9. Frequency characteristics of the sound recorder: A in the no load condition with the cutter oscillating freely, the resonance point is here about 3500 cycles; B during normal running with the cutter engraving a sound-track, where, owing to the additinal directional force due to the film, the resonance point has been displaced to about 5000 cycles and the sensitivity of the system, i.e. the amplitude at an equivalent energising current has dropped by about 3 dB (3 decibels corresponding to a factor $10^{0.3} = 2$); the damping due to the film has here caused a marked flattening of the resonance peak. The deviations from the horizontal still present in curve B are eventually largely compensated by choosing a suitable characteristic for the amplifier. The dotted curve C shows the frequency characteristic of the whole apparatus used for sound recording and reproduction.

tioned also has an elastic force which increases the directional force of the whole vibrating system. As a result there is an increase in the resonance frequency. In addition the sensitivity of the system is reduced, which tends to lower the position of the whole curve. By appropriately dimensioning the clamping arrangements of the armature, the potential increase in the resonance frequency has already been taken into consideration; when running freely the resonance frequency is at about 3500 cycles/sec, being increased during normal operation by the directional force caused by the film to about 5000 cycles (cf. curves A and B in fig. 9). The drop in the characteristic curve in the range between 100 and 1000 cycles/sec is due to the iron losses which increase with the frequency.

Possible Causes of Distortion

In the reproduction of music the principal aim is to reproduce the mixture of component sound vibrations without any distortion. To achieve this the intensity ratio of all component notes must be maintained, in other words the frequency characteristic for the whole apparatus must be as closely horizontal as possible. Slight deviations from the horizontal are not very disturbing, and only appreciable differences actually become apparent as variations in timbre. Moreover, such deviations of the frequency characteristic from the horizontal which occur in one part of the apparatus, e. g. in the sound recorder as in curve B of fig. 9, can be readily compensated in other parts of the apparatus, e.g. in the valve amplifier. Thus the broken curve C in fig. 9 which represents the frequency characteristic of the whole sound-recording and reproducing apparatus is almost horizontal.

In addition to variations in timbre, a further type of distortion is that due to the formation of new notes with frequencies which were not originally present in the incoming sound vibrations. This form of distortion makes its appearance when the output amplitude (for each individual frequency) is not absolutely proportional to the input amplitude; it is therefore termed "non-linear distortion".

Thus, in the case of the sound recorder, the recorded amplitude A must be proportional to the intensity of the energising current I in the armature coil, i.e. $A = f(I)$ must be a linear function. If this is not the case, and if the function contains for instance a quadratic term, on substituting for I a vibration $I_o \sin \omega t$ we get $f(I)$ containing an extra term $\sin^2 \omega t$, i.e. a term $\cos 2 \omega t$ [7]). Hence A contains in addition to the initial frequency ω also a second harmonic 2ω. If the deviation of function $f(I)$ from linearity is still more marked, a whole series of harmonics of each individual note in the frequency mixture of the incoming musical vibrations can occur. If, furthermore, we substitute for I the sum of several sinusoidal vibrations (which corresponds to the case occurring in practice), e.g. $I_1 \cdot \sin \omega_1 t + I_2 \cdot \sin \omega_2 t$, A will contain, among

[6]) In measurements made to obtain these characteristics a constant current with a continuously increased frequency is passed through the energising coil of the sound recorder and the cutter allowed to trace the corresponding track. Measurement of the amplitudes of this sound-track by means of a microscope gives the characteristic directly (amplitude as a function of the frequency). The sound recorder thus traces its own characteristic on the film.

[7]) Since $\sin^2 a = \frac{1}{2} (1 - \cos 2 a)$.

others, also a term of frequency ($\omega_1 - \omega_2$) and another of frequency ($\omega_1 + \omega_2$). In addition to the harmonics (overtones) already referred to, summation and differential tones are thus also obtained. These contribute a sound which stands, in view of harmonics, entirely apart from the original music to be recorded and hence may considerably harm the music when reproduced.

A "non-linear" distortion is thus more disturbing to the ear than a distortion due to the frequency characteristic not being quite horizontal (variation in timbre alone, see above). Moreover, it is practically impossible to compensate a non-linear amplitude characteristic of one component of the transmission circuit in one of the succeeding components, such as can be done with a non-horizontal frequency curve. It is essential, therefore, that every trace of non-linearity is as far as possible eliminated in each component separately.

Various causes might be thought of in the Philips-Miller sound recorder, for a deviation from the linear relationship between the recorded amplitude and the energising current. In the main, three points require consideration. Firstly, such deviation may be caused by the magnetic conditions. In order to make the amplitude a of the armature proportional to the energising current I, the alternating field ΔH generated by I in the air gap must, as follows from equation (6), be proportional to I. But the connection between the intensity of this alternating field in the air gap and the energising current is determined by the whole magnetic circuit, which is composed of the air gap and the iron components. In a magnetic circuit through air alone the required proportionality would always be maintained, as air has a constant permeability or, in other words, a constant magnetic resistance to the passage of the magnetic flux. In iron, however, this magnetic resistance is well known not to be constant; it depends on the field strength, so that in a magnetic circuit through iron alone the connection between the alternating field and the energising current will deviate more or less from linearity according to which part of the magnetisation curve is under consideration. As the magnetic resistance of the circuit as a whole is arrived at by compounding the "linear" resistance in the air gap and the "non-linear" resistance in the iron, it is evident that the required linearity can be approached by making the magnetic resistance of the iron component small compared with the resistance in the air gap. This is achieved by selecting a type of iron with a high alternating-current permeability [8]) and by making the iron component of ample cross-section, particularly the pole-pieces. To ensure high permeability through the iron it is naturally necessary to work sufficiently below the saturation range on the magnetisation curve, i.e. with field strengths at which the permeability is still very large.

A second possible cause of non-linear distortion is that the various parts of the mechanical vibrating system subject to torsion and transverse bending may, during vibration, become deformed beyond the limit of proportionality. As this is most liable to occur at sharp corners and edges where the stresses may attain high peak values, all edges and corners (particularly on the torsion axis and clamping units of the armature) have been carefully rounded off. Experimental tests by loading the armature with weights (up to 2 kg) and measuring with the microscope the bending produced, have shown that Hooke's law is satisfied within reasonable limits up to the highest forces which may occur in practice.

Finally, non-linear distortion may also be produced by the damping due to the film not being linear, i.e. the resistance applied by the film is not strictly proportional to the velocity of the cutter [9]). There were indeed certain indications that a slight distortion during recording was actually due to this cause, since it was found on recording a vibration with a frequency of a half or a third of the resonance frequency that a suggestion of the latter was also present in the recorded track. Thus, up to a point the second and third harmonics of the oscillations to be recorded were also generated in the sound recorder (as already pointed out, this is in fact the nature of a non-linear distortion). To eliminate this undesirable effect of non-linear damping due to the film, the vibrating system was given an additional (linear) damping, so that the damping due to the film constituted only a fraction of the total damping, and its non-linearity no longer had a disturbing effect. The extra damping was applied by providing the armature with a type of vane (Fl) on the side opposite to the lug, this vane during oscillation of the armature moving in a plastic medium (R). The arrangement of the vane and the damping medium in the chamber formed by the pole-pieces and the magnet block is shown in *fig. 10*; to increase the adhesion between

8) In the case of the nickel-iron alloy chosen, μ is > 600 when the induction in the iron (pole-pieces), which is numerically roughly equal to the field strength in the air gap, (dispersion not being taken into account), is about 10000.

9) E. g. it might also depend on the depth of the track.

the damping medium and the vane the latter is given a number of perforations.

Fig. 11 shows the relationship between the current intensity I in milliamperes (at a frequency of 200 cycles) in the armature coil (1200 turns) and the amplitude a in millimetres, which the sound recorder traces at different current intensities on the "Philimil" strip.

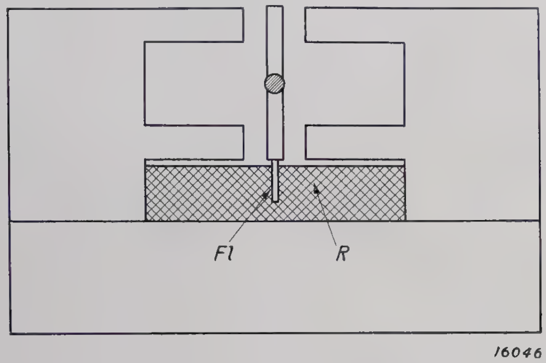

Fig. 10. Application of additional damping force to reduce the effect of a non-linear damping due to the resistance produced by the film. To the armature a vane *Fl* (see also fig. 7) is attached moving in a demping medium *R* which has been specially evolved for this purpose and with which the chamber formed by the pole-pieces and the magnet is filled.

It is seen that by adopting the various measures described, viz, reducing the share of the iron in the total resistance of the magnetic circuit, avoiding peak stresses in components exposed to torsion, and reducing the effect of non-linear damping due to the film, true linear recording of the sound waves is obtained.

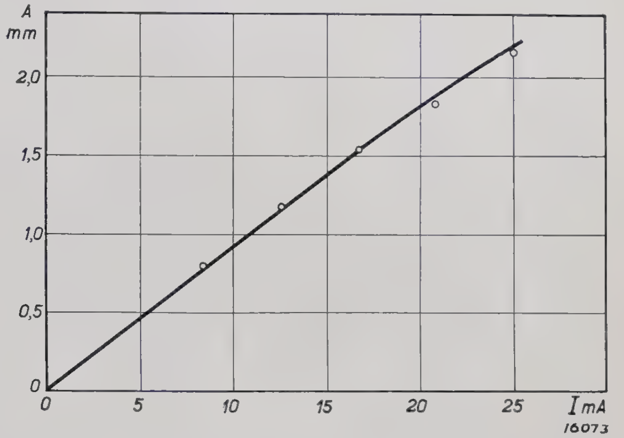

Fig. 11. Relationship between the amplitude A (in mm) traced by the sound recorder and the current intensity I (in milliamps) through the energising coil at a frequency of 200 cycles/sec. This line is nearly a straight line, thus, the required proportionality is satisfactorily fulfilled.

THE DEFINITIONS OF BRIGHTNESS AND APPARENT BRIGHTNESS AND THEIR IMPORTANCE IN ROAD LIGHTING AND PHOTOMETRY

By P. J. BOUMA.

Summary. In illumination technology brightness is defined as the magnitude $H = C \int E(\lambda)\, V(\lambda)\, d\lambda$, where C is a constant, $E(\lambda)$ the relative spectral distribution and $V(\lambda)$ the international standard visibility curve. In the investigation of various problems in physiological optics and particularly problems relating to road lighting it has, however, been found necessary to introduce another quantity, the so-called apparent brightness h, which is more closely related to the sensation of brightness which the eye experiences. The apparent brightness h is defined as follows: If two surfaces appear to the eye to be "equally bright" we assume that they have the same h value. At high brightness levels (daylight) the two quantities are identical, but at low brightnesses (at the level of road lighting and lower) there are considerable differences between them. The significance of these differences in photometry, physiology and road lighting are briefly discussed.

In dealing with problems of road lighting, the concepts of brightness and apparent brightness are of paramount importance. It is therefore necessary to define these two quantities as accurately as possible, particularly as considerable misapprehension and contradiction in the literature relating to this subject exist due to the insufficient differentiation between these two terms.

What does direct experience teach us ? If in the first place we limit ourselves to light of a specific spectral composition (i.e. of a specific colour), the eye can establish whether two surfaces which radiate this light are equally bright; if this is not the case we can state which of the two surfaces is the brighter. Direct observation cannot give us more information, and in particular the eye is unable to assign by mere inspection a quantitative ratio to two unequal sensations of brightness. We cannot say: "This surface is six times brighter than that one", although we can state: "This surface is brighter than that one". Experience further informs us that a particular surface is the brighter the more energy it emits of the type of light in question.

From this it follows that we can represent the "brightness" numerically, without contradicting our direct experience of the sensation of brightness, by a magnitude H which is proportional to the energy E which the surface radiates per second from each unit of surface and in each unit of solid angle, thus:

$$H = k\,E \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The constant k is as yet still quite arbitrary [1]).

The matter becomes much more complicated when we have to compare the luminosities of two surfaces which radiate light of different spectral composition (different colour).

From measurements on the optical bench it can readily be established that the eye can determine without difficulty which of two surfaces with considerable differences in brightness is the brighter; if the photometer is adjusted in such a way that the difference in brightness is very small, comparison is rendered very difficult by the difference in colour. But after a little practice it is possible to adjust sufficiently accurately two surfaces with different colours to equivalent brightness values. Now what are the results on making such "heterochromatic" adjustments to obtain an equivalent brightness ?

Restricting ourselves in the first place to the spectral colours and determining for the various wavelengths λ the energies $E(\lambda)$ which are required to obtain the same sensation of brightness, we find that the minimum amount of energy required for this purpose is for the yellowish green (5550 Å), whilst considerably more energy is required at the two ends of the spectrum. In other words the eye responds most sensitively to yellowish-green light; it is least sensitive to red, blue and violet, and is quite unresponsive to wavelengths outside the range between 3100 and 7600 Å. A good measure

[1]) Theoretically we could have equally well selected other definitions for the brightness, e.g. $H = k \log E$. Such definitions are frequently found in physiological and opthalmological literature. The advantages of the definition adopted by us (which is that in general technical use) are purely of a practical nature as the calculations are much simplified by it.

for ocular sensitivity or visibility can be assumed to be the ratio $1/E(\lambda)$, i.e. the reciprocal of the energy which must be utilised to obtain a specific sensation of brightness. Generally these magnitudes are multiplied by such a constant as will make the maximum value of the sensitivity of the eye exactly equal to unity. *Fig. 1* shows the ocular sensitivity $V(\lambda)$ obtained in this way, plotted as a function of λ. (Cf. curve A in fig. 6, Philips techn. Rev. 1, 106, 1936.)

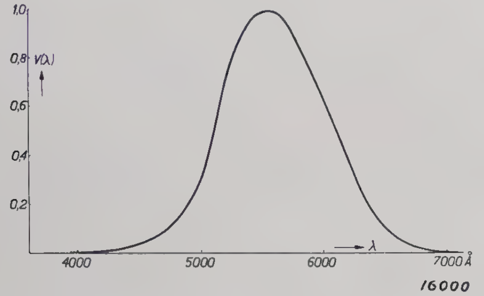

Fig. 1. The standard visibility or sensitivity curve of the eye. $V(\lambda)$ is, except for a constant factor, the reciprocal of the energy required at different wavelengths to produce an equal brightness.

The curve has now been determined for a specific sensation of brightness. If we repeat these measurements for other brightness levels a striking fact emerges, viz., that over a wide range of brightness values (which inter alia includes the whole range of daylight) the same curve is always obtained, in other words the visibility ratio of the eye is constant for various wavelenghts over a wide range of brightness. The visibility curve obtained for this range — which we shall term the standard visibility curve — has been determined with great accuracy by Gibson, Tyndall and others and has been taken as the international standard.

On this standard curve $V(\lambda)$ the definition for "brightness" is based on the following:

For a spectral colour of wavelength λ_0 the luminosity is

$$H = C\ V(\lambda_0)\ E(\lambda_0) \quad \ldots \quad (2a)$$

for composite colours made up of a number of spectral colours (line spectra, e.g. of gaseous discharge lamps):

$$H = C \sum_k V(\lambda_k)\ E(\lambda_k) \quad \ldots \quad (2b)$$

and for continuous spectra (sunlight, incandescent lamps):

$$H = C \int V(\lambda)\ E(\lambda)\ d\lambda \quad \ldots \quad (2c)$$

Here $E(\lambda_k)$ is the energy of wavelength λ_k which is radiated per second from unit surface and in unit solid angle in the direction of the eye, $E(\lambda)\ d\lambda$ the energy which is radiated in the range of wavelengths $\lambda \rightarrow \lambda + d\lambda$, and C is a universal constant whose magnitude depends only on the choice of unit for the brightness and for the energy.

The most common brightness units are the candle per sq. metre, the candle per sq. cm (stilb), apostilb, milli-lambert and the candle per sq. ft., which are inter-regulated as shown in the following table:

Table I

	candles per sq. metre	candles per sq. cm	apostilb	milli-lambert	candles per sq. ft.
1 candle per sq. metre =	1	10^{-4}	π	$\frac{\pi}{10}$	0.0929
1 candle per sq. cm =	10^4	1	$\pi.10^4$	$\pi.10^3$	929
1 apostilb =	$\frac{1}{\pi}$	$\frac{1}{\pi}10^{-4}$	1	1/10	0.0296
1 milli-lambert =	$\frac{10}{\pi}$	$\frac{10^{-3}}{\pi}$	10	1	0.296
1 candle per sq. ft. =	10.76	$1.076 \cdot 10^{-3}$	33.8	3.38	1

If H is expressed in candles per sq. cm and E in watts per sq. cm per unit solid angle, C becomes 621 (this figure is termed the mechanical equivalent of light, and represents the brightness of a surface which from each sq. cm of surface and in each unit of solid angle radiates in the direction of the eye 1 watt of monochromatic light with the wavelength of maximum visibility).

Now experiments have shown that in the range of brightnesses in which the standard visibility curve applies, the definitions of brightness (2) are in no wise in contradiction with our subjective sensation of brightness, i. e. two surfaces to which on the basis of (2) we ascribe the same brightness impress the eye as being "equally bright" [2]). In what way is the "range of brightness" frequently mentioned above limited? And what deviations occur outside this range?

In an upward direction the range is limited by the range where the brightnesses are so great that their glaring effect prevents the eye from making a comparison of brightness values.

Of more importance to us is the lower limit of the range as it lies in the neighbourhood of the brightnesses obtained with road lighting systems. It is indeed found that at brightnesses below approx. 3 candles per sq. metre visibility curves are obtained of a different type to that shown in fig. 1; the

[2]) This general statement embraces various characteristics of the eye as regards the comparison and addition of brightnesses, an aspect which we cannot enter into at the present juncture.

visibility curve becomes displaced at diminishing brightnesses towards the blue, at first slowly, then more rapidly. The principal part of the displacement takes place in the brightness range between 0.3 and 10^{-3} candles per sq. metre. At still lower brightnesses a further slight displacement occurs, and finally the curve assumes a constant shape again at about 3.10^{-5} candles per sq. metre (*fig. 2*)[3]. The maximum becomes displaced from 5550 Å to

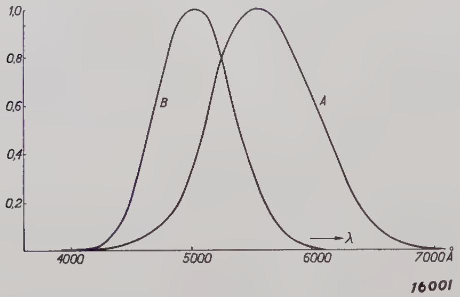

Fig. 2. Various visibility curves:
A. for high brightness levels (standard curve),
B. for extremely low brightnesses.
For intermediate brightness levels (road lighting) an intermediate curve applies.

5050 Å. If we remember how a visibility curve is obtained experimentally, we see that this displacement of the curve signifies that the ratio of the energies which must be utilised by different colours in order to obtain a visual sensation of equivalent brightness is dependent on the brightness level (thus, for instance, the same amount of energy is required for the wavelengths 5300 and 5800 for a specific high brightness, whilst for an extremely low brightness twelve times more energy is required for the second wavelength than for the first).

This extremely important fact, which is termed the Purkinje effect, can be expressed in various other ways, e.g.:

Two surfaces emitting light of different colours and appearing to be equally bright do not retain this appearance of equivalence when both energies are divided by the same factor, or:

If two surfaces have the same numerical value for the brightness according to definition (2), they need not always produce the same brightness impression, and hence:

The interpretation of brightness according to definition (2) no longer coincides, outside the range of validity of the standard visibility curve, with the concept of brightness deduced from everyday experience.

It thus follows that to avoid a loose interpretation we must adopt two different concepts, viz., brightness and apparent brightness.

Brightness H is defined — for every range of brightness — as the numerical value given by definition (2). This definition has already been adopted as the international standard. Our first requirement as regards the apparent brightness h is that two surfaces which produce the sensation of equivalent brightness must also have the same value of h. It follows from this that the plotting of the visibility curve by the method described above constitutes in all cases a measurement of energies, which must be radiated at different wavelengths in order to create the same apparent brightness.

This "definition of equality" (which answers the question: When have two surfaces the same apparent brightness ?) is already adequate in itself for dealing with a large number of problems. In other cases it will be, however, of great advantage if we can also assign a definite numerical value to the apparent brightness, i.e. obtain a "quantitative definition" answering the question: How great is the apparent brightness of this surface ? Exactly as when assigning numerical values to the brightness (see footnote [1]) there is a certain latitude in choosing this "quantitative definition". We select the following definition:

The apparent brightness of a surface which radiates light of any arbitrary colour has assigned to it the same numerical value as the brightness of a surface which emits monochromatic light of wavelength 5350 Å[4]) which gives the same brightness-impression as the surface under investigation (König, Bouma).

We can express this complete concept of apparent brightness also in somewhat different terms, viz., as follows:

For monochromatic light of 5350 Å the brightness and the apparent brightness have according to definition the same numerical value. The values for light of different colours are determined by the rule: Two surfaces have the same apparent brightness if they appear to the eye to be "equally bright".

Expressed in this way it is seen immediately that in the range above 3 candles per sq. metre two surfaces which have the same brightness also have the same apparent brightness, and that hence above 3 candles per sq. metre the brightness and the apparent brightness completely coincide. The very marked difference which can occur in these two

[3]) These curves have also already been published in Philips techn. Rev. 1, 106, 1936.

[4]) This wavelength of 5350 Å has been chosen to facilitate correlation with König's measurements.

factors at low brightness levels is shown by *fig. 3*, where the lines of equal apparent brightness h are plotted graphically with the wavelength λ along the abcissa and the brightness H along the ordinate. It is seen for example that to obtain the same apparent brightness $h = 3.10^{-4}$ candles per sq. metre a luminous density is required for red light (6500 Å) about 140 times greater than for blue light (4500 Å).

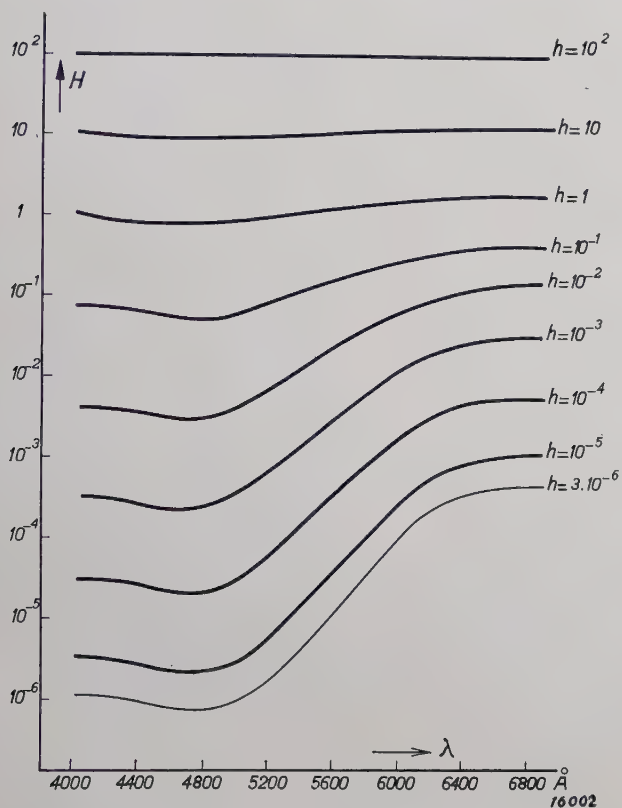

Fig. 3. The relationship between brightness (H) and apparent brightness (h) for monochromatic light: in an H-λ diagram the lines of constant apparent brightness are drawn; the curvature of these lines indicates the occurrence of the Purkinje effect. Both H and h are given in candles per sq. metre. The line $h = 3.10^{-6}$ candles per sq. metre represents approximately the absolute threshold value.

The physiological cause of the Purkinje effect is very probably to be sought in the functioning of the two different light-sensitive elements of the eye, the cones and rods (cf. also the article in Philips techn. Rev. 1, 102, 1936). Above 3 candles per sq. metre vision is due practically solely to the cones which give us the standard visibility curve (A in fig. 2); below about 3.10^{-5} candles per sq. metre only the rods are functioning and these give the visibility curve B in fig. 2. At intermediate brightness levels there is a combined functioning of both elements, cones and rods, to produce vision, and the visibility curve obtained for this range is therefore situated between curves A and B in fig. 2. As the rods and cones are irregularly distributed over the retina, it is evident that for the accurate definition of apparent brightness it is in fact also necessary to state the size and shape of the field of vision, and for this purpose we choose two semicircles in contact with each other with an angular diameter of at least 6 deg. (a smaller diameter would partially exclude the rods, whilst an increase in the diameter would not affect the results of measurement).

We cannot conclude this discussion without indicating the practical value of the concepts of brightness and apparent brightness in certain branches of science and engineering.

1. Photometry. The principal purpose of photometry is the measurement of brightnesses and the calculation of other technical light magnitudes (candle power, luminous flux, etc.) from the measured brightnesses. The methods of measurements [5]) employed are divided into two groups:

a) Those methods in which the eye is used as a measuring instrument, as in the flicker photometer. True brightnesses are only obtained by these methods when the values are above 3 candles per sq. metre. At lower brightness levels values are found which in general agree with neither the brightness nor the apparent brightness.

b) Those methods in which the eye is not used directly for measuring purposes, e.g. in adapting a photo-electric cell to the standard visibility curve. Accurate brightness values are obtained with these methods also below 3 candles per sq. metre.

2. Physiology, the description of the characteristics of the eye. Many physiological properties (contrast sensibility, diameter of pupil, state of adaptation, etc.) are determined principally by the apparent brightness and not by the brightness. Thus if we plot the contrast sensibility as a function of the brightness we get very different curves for various colours; but if we plot the apparent brightness along the abcissa the curves agree fairly closely. We thus see that here, by introducing the notion of apparent brightness, we obtain a more comprehensive survey of the results of measurements and means for simplifying the laws regarding the behaviour of the eye.

3. Road lighting. In this connection the two concepts discussed are of importance in various directions. The brightness levels obtained with road lighting systems are of the order of 0.06 to 1.5 candles per sq. metre i.e. they are in a range in which the Purkinje displacement becomes appreciable. As an example showing how the

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[5]) Cf. Philips techn. Rev. 1, 120, 1936.

quality of road lighting can be affected by this factor, we can compare sodium light and white light (from an ordinary incandescent lamp). The result of the Purkinje effect is as follows:

If two roads are illuminated with the same and sufficiently high brightness, one with sodium light and the other with white light, it is found that vision is better on the road illuminated with sodium light. Now if the levels of illumination of the two roads are reduced by the same factor, vision deteriorates much more quickly in the road illuminated with sodium light than in that illuminated with white light. The reason for this is that although the brightnesses in the two roads remain the same, the apparent brightness of the "sodium road" diminishes more rapidly than that of the "white road". We conclude from this that the illumination in the sodium road is only better when the brightness remains above a certain lower limit (about 3 candles per sq. metre).

This same phenomenon of "more rapid darkening" of the sodium road causes dark objects in the sodium road to stand out more clearly from the bright background than is the case in the white road, in other words the appearance of greater richness of contrast with the sodium light is also explained by the Purkinje effect and the difference between apparent brightness and brightness connected with it. We shall discuss this phenomenon in greater detail in a later article.

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AN OSCILLOGRAPH APPARATUS

Summary. A cathode-ray oscillograph which has been constructed by Philips is described, by means of which the fluctuations of voltages from 5 millivolts upwards can be studied in a frequency range from 10 to 500000 cycles.

Introduction

An electrical oscillograph can be usefully employed for rendering visible tbe fluctuations of a specific voltage. As already indicated in previous issues of this Review [1]) the cathode-ray oscillograph has now been developed to a useful technical apparatus. In this article, a description is given of an oscillograph (type G.M. 3150) evolved by Philips.

This oscillograph contains an amplifier by means of which the voltage under investigation is raised to the value required for feeding to the deflector plates V of the cathode-ray tube (*fig. 1*). The apparatus also incorporates a time-deflection (or relaxation voltage) unit, which furnishes the saw-tooth voltage [2]) for the plates H for periodically deflecting the cathode ray in a horizontal direction. In place of the saw-tooth voltage, a voltage from an external source can also be applied to the plates H. The saw-tooth voltage can be synchronised with the signal transmitted by the amplifier or with a signal transmitted from any external source or also with the alternating current mains supply. Two anode rectifiers are also incorporated in the apparatus for furnishing the direct voltages for the cathode-ray tube, for the amplifier and for the relaxation voltage (time-deflection) unit. With this oscillograph, time diagrams can be produced, with practically no distortion, of voltages from 5 millivolts upwards and with frequencies from 10 to 500000 cycles.

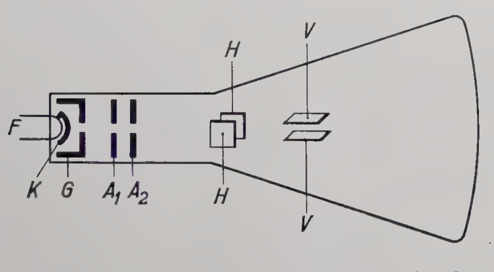

Fig. 1. Diagram of cathode-ray tube. K = cathode; F = filament; G = control electrode; A_1 and A_2 = first and second anode; H and V = pairs of plates which can impart horizontal and vertical deflections respectively to the cathode ray.

Feed Circuit for the Cathode-Ray Tube

Fig. 1 shows the circuit connections of the cathode-ray tube (type No. 3957) which is employed in the oscillograph. The various direct voltages, which must be applied to the control electrode and the anodes, are furnished by a rectifying valve L_2 (*fig. 2*) with smoothing condenser C, and can be tapped with the required magnitudes from a resistance (R_1, R_4). The circuit (fig. 2) is so arranged that the second anode A_2 is earthed and the indirectly-heated cathode K has a negative bias of about 12000 volts compared with the second anode. The potential of the control electrode G, which is slightly lower than that of the cathode K, and the potential applied to the first anode A_1 can be regulated. By altering the tapping on R_4 the intensity of the electron beam which the control electrode G allows to pass is altered, whilst by means of R_1 the definition of the fluorescent spot can be adjusted. In addition to the usual deflecting voltages an adjustable bias is also applied to the pairs of plates H and V, by means of which the spot can be adjusted to the centre of the fluorescent screen. The front panel of the oscillograph housing (*figs. 3a* and *3b*) contains inter alia the knobs R_1 and R_4 by means of which the definition and the brightness respectively of the spot can be altered. Knob R_4 also operates the switch S_5 with which the primary winding of the feed transformer is switched on and off, i.e. the whole apparatus is connected up to or disconnected from the supply.

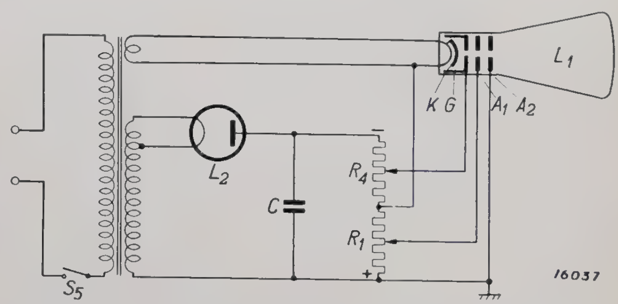

Fig. 2. Simplified feed circuit of cathode-ray tube. By means of R_4 and R_1 the brightness and sharpness respectively of the fluorescent spot can be varied.

Time Deflection

The electrical voltage, whose time diagram is to be reproduced on the fluorescent screen, is applied to the plates V (fig. 1) which deflect the cathode ray in a vertical direction. To achieve this a voltage must at the same time be applied to the plates H which deflect the cathode ray in a horizontal

[1]) Philips techn. Rev. **1**, 33 and 91, 1936.
[2]) Cf. Philips techn. Rev. **1**, 16, 1936.

direction; this voltage must vary linearly with the time and, after the elapse of an integral number of periods of the voltage under investigation, must return rapidly to its original value, and then again

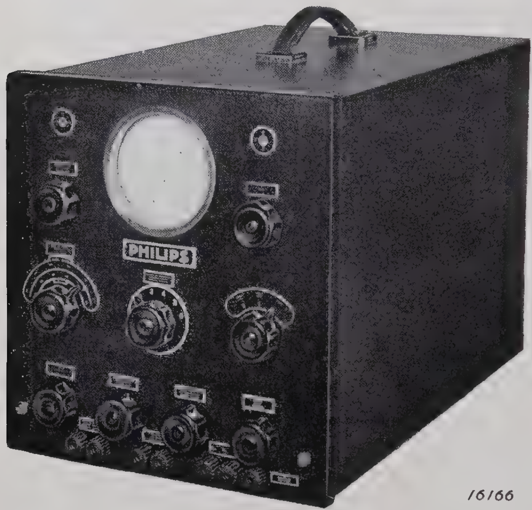

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Fig. 3a. General view of the oscillograph unit.

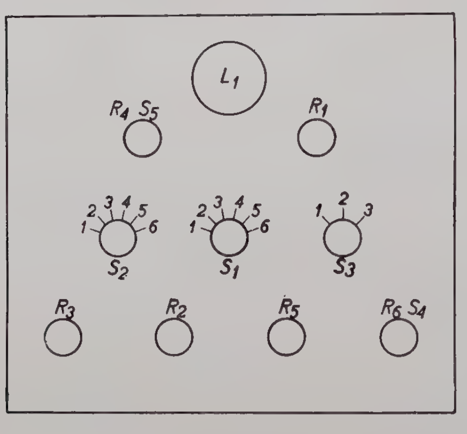

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Fig. 3b. Front view of oscillograph unit.
R_1 controls the sharpness of the fluorescent spot.
R_2 controls the width of the time diagram.
R_3 controls the intensity of the synchronising signal.
R_4 controls the brightness of the fluorescent spot.
R_5 controls the frequency of the saw-tooth voltage.
R_6 controls the amplification of the voltage under investigation.
S_1 serves for rough regulation of the frequency of the saw-tooth voltage.
S_2 determines what voltage is applied to the deflector plates H.
S_3 determines which method of amplification is used.
S_4 changes over the amplification.
S_5 connects up the feed transformer.

increase linearly with the time in exactly the same way. This so-called "saw-tooth voltage" for the plates H is furnished by the relaxation voltage (or time-deflection) unit.

The main details of the circuit in the relaxation voltage unit are shown in *fig. 4*. An anode rectifier furnishes a direct voltage of about 400 volts across the terminals A and B of the relaxation voltage unit. Across the terminals C and D a saw-tooth voltage as far as possible of rectilinear form is required. To do this the potential at the condenser V_F must increase linearly with the time. This cannot be done by charging the condenser V_F through a resistance, since owing to the increase in voltage at the condenser the charging current would drop during charging. One characteristic of a pentode, however, is that the anode current is practically independent of the anode voltage over a wide range. This property is employed in the relaxation voltage unit. At the beginning of a period the condenser V_F is uncharged, whilst the anode voltage is applied to V_G. No voltage is then applied to the pentode L_7, so that it passes no current, although pentodes L_8 and L_9 do so. The condenser V_F is charged with a constant current intensity through L_8. The voltage V_F across the terminals B and D thus increases linearly with the time (*fig. 5*) and this is the voltage which is applied to valve L_7. When this voltage has increased to a certain value an anode current will also flow through L_7, but at the same time the screen grid S of this valve will be carrying a current which can flow away through r_1. As a result a voltage-drop occurs at r_1 which causes a diminution of the voltage at the two plates of the condenser V_G charged to the anode voltage. The potential at the negative plate of V_G thus drops below the voltage of the common negative conductor AC. A current will then flow through r_3 which will discharge the condenser V_G, whilst the control grid of the pentode L_9 will acquire a negative potential (V_9 in fig. 5). The ratings of the apparatus have been so chosen that this voltage-drop at the control grid of L_9 is large enough to reduce the passage of current through L_9 to practically zero (I_9 in fig. 5). The anode of L_9 and hence the control grid of the pentode L_7 are thus reduced to nearly the same voltage as the anode of L_7. This pentode is thus rendered a very good conductor and the condenser V_F will become rapidly discharged through it (L_7 in fig. 5). Hence as soon as the condenser V_F commences to become discharged through L_7, the circuit provided with the pentode L_9 will ensure that this discharge takes place very rapidly, after which the whole process recommences from the beginning.

The voltage of the anode of L_8 is passed through terminal D to one of the deflector plates H of the cathode-ray tube. It has the requisite saw-tooth characteristic for this purpose as it is the difference between the direct voltage at the terminals A and B and the voltage V_F in fig. 5. The other plate H receives a specific adjustable potential difference

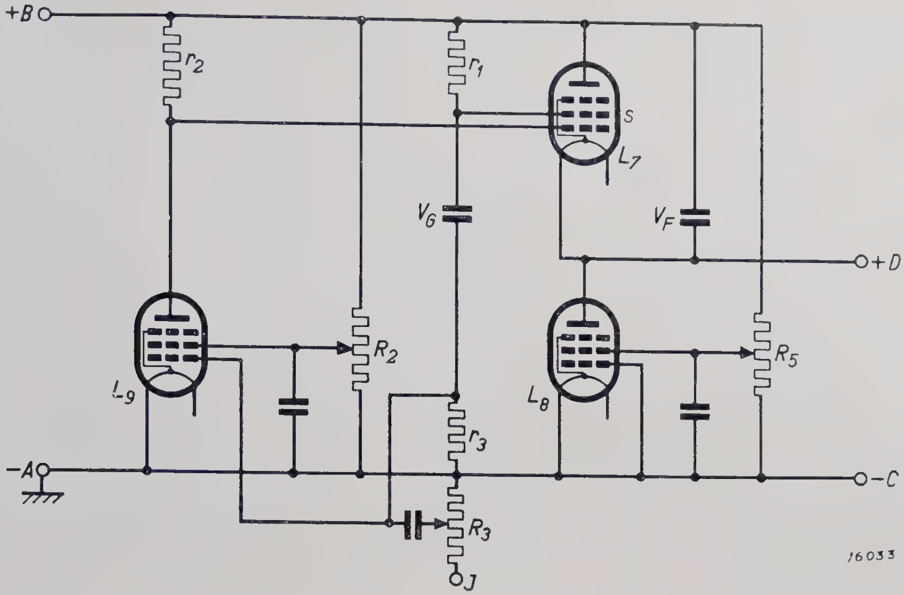

Fig. 4. Circuit details of the time-base unit. A constant direct voltage of about 400 volts is applied across terminals AB and a synchronising signal to terminal J. The saw-tooth voltage for the deflector plates H is taken from terminals CD. L_7 is a pentode AL4 Pentodes AF7 are used for L_8 and L_9.

with respect to terminal C such that the fluorescent spot travels to and fro over the required area of the screen. If the screen-grid voltage for L_9 is tapped at various points of R_2, the anode current I_9 of L_9 will assume different values, whereby the screen grid of L_7 will receive different voltages. This will also alter the voltage at which the condenser V_F becomes discharged through L_7. Using R_2, regulation is thus obtained of the voltage fluctuations at D and hence of the magnitude of the horizontal deflections of the cathode ray in the cathode-ray tube. Knob R_2 in fig. 3 serves for adjusting the width of the time diagram on the screen. The time taken for the condenser V_F to become once charged depends on its capacity. The frequency of the relaxation voltage is therefore easy to adjust in this unit by merely inserting condensers of different capacity for V_F. This is done by means of switch S_1 which has six different settings, as shown in fig. 3b. Naturally in this way only rough regulation of the frequency of the saw-tooth voltage can be obtained, and must be followed by fine regulation which is carried out by tapping from different points of resistance R_5 the voltage for the screen grid of L_8 by means of which the charging current of the condenser V_F is regulated.

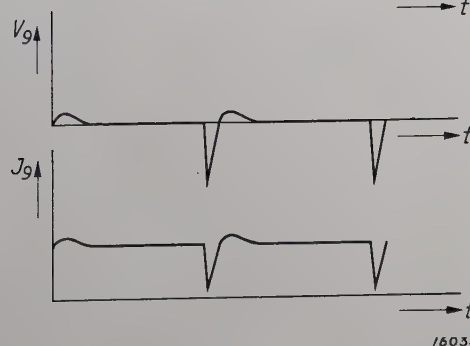

Fig. 5. Time diagrams of voltage at condenser V_F, of the anode current I_7 of pentode L_7, of the voltage V_9 at the control grid of L_9 and of the anode current I_9 of the pentode L_9.

To ensure that at different frequencies of the saw-tooth voltage the ratio between the charging and the discharging periods remains practically constant, S_1 alters not only the capacity of V_F but also alters that of V_G at the same time. In this way the lability of the circuit by means of which the condenser V_F can be discharged at such a rapid rate (I_7 in fig. 5), is maintained even after altering the capacity of V_F. In this circuit the function of the pentode L_9 is therefore to make the resistance of the pentode L_7, which is in parallel with the condenser V_F, suddenly very small, so that condenser V_F becomes very rapidly discharged through the pentode L_7 which practically shorts the condenser. The instant this sudden discharge takes place is very easily affected [3]) in this circuit by small changes which may for instance occur

[3]) Cf. D. M. Duinker, Philips techn. Rev. 1, 14, 1936.

in the voltage at certain points of the circuit. We can regulate the moment at which the discharge current I_7 commences to flow by applying a voltage over terminal J (fig. 4) to the control grid of L_9, which makes V_9 sufficiently negative either slightly earlier or later [3]) so that the anode current I_9 is reduced practically to zero (fig. 5). The voltage applied to J, which is drawn from the amplifier or the mains or an external supply provided for this purpose, thus determines the correct instant at which the condenser F becomes very rapidly discharged; it thus serves as a so-called synchronising signal, in other words it ensures that the saw-tooth voltage is always synchronised with either the magnitude under investigation, or the alternating-current mains or a periodic current applied from an external source. The required intensity of the synchronising signal is regulated by means of R_3.

Fig. 6 shows how, with the aid of switch S_2, different potentials can be applied to the deflector

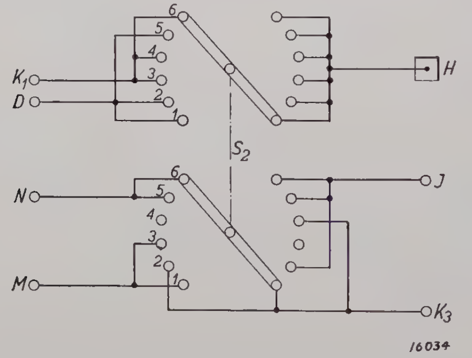

Fig. 6. Diagram of the six different combinations between the deflection settings of the cathode ray and the synchronising settings which can be obtained with the switch S_2. J is the terminal over which the synchronising signal is passed to the time-base unit, and H is the plate which imparts a horizontal deflection to the cathode ray. To terminals D, N and M are applied respectively the saw-tooth voltage, a voltage in phase with the a.c. mains and a synchronising signal from the amplifier. Through terminals K_1 and K_3 a deflection voltage or a synchronising signal from an external source can be passed in or out.

plates H and various synchronising signals can be applied to the terminal J (cf. fig. 4).

Position 1: Saw-tooth voltage (D) applied to the deflecting plate (H); synchronising signal (J) taken from the amplifier (M). This is the normal setting.

Position 2: Saw-tooth voltage (D) applied to the deflecting plate (H); external synchronising signal (J) applied over terminal K_3. This setting is used to synchronise with a specific frequency, when for instance the signal under investigation consists of a combination of different vibrations.

Position 3: External deflecting voltage (H) applied through terminal K_1; synchronising signal from the amplifier (M) passed outwards over terminal K_3. By this means a different relaxation voltage unit to that incorporated in the apparatus can be put in circuit.

Position 4: External deflecting voltage (H) applied over terminal K_1; synchronising signal (J) cut out to prevent this signal causing distortion.

Position 5: Saw-tooth voltage (D) applied to deflector plate (H); synchronising signal (J) taken from the alternating current supply (N), thus synchronising with 50 cycles.

Position 6: External deflecting voltage (H) applied through terminal K_1; synchronising signal from the a.c. mains (N) passed outwards over terminal K_3. This setting differs from setting *5* only in that the built-in time-base unit is replaced by another.

Amplifier

Fig. 7 shows a simplified diagram of the various circuits by which the signal to be plotted by the oscillograph is applied to the plates V of the cathode-ray tube; these plates have to produce a vertical deflection of the electron beam. The same anode rectifier which feeds the time-base unit also furnishes the amplifier with a direct voltage of about 400 volts across the terminals A and B, of which A is earthed. The signal under investigation is applied across the terminals K_5 and K_7, of which the latter is earthed. If switch S_3 is moved into position *1*, a signal for feeding to the amplifier can be taken from the resistance R_6. When a current flows through R_6, which causes pronounced distortion of the signal voltage under examination, the signal must be applied across K_6 and K_7 so that it reaches the control grid of the pentode L_2 directly through the condenser C_1. The regulating knob of R_6 (cf. fig. 3) is then turned to the left, whereupon S_4 is switched off and R_6 no longer carries current either. Normally the voltage tapped from R_6 passes to the control grid of L_2 through C_1. The screen grid has a specific potential difference with respect to the cathode, whilst the collecting grid is directly connected to it.

The alternating voltage generated at resistance r_4 by the anode current of L_2 is now an amplification of the signal and at position *1* of S_3 is applied to the control grid of pentode L_3 through the condenser C_2. If the original signal is powerful enough it can also be applied directly to C_2 by moving S_3 into position *2*, the first amplifying stage with the valve L_2 being cut out. At settings *1* and *2*

of S_3 the anode of L_3 is connected through condenser C_4 to terminal *M*, from which the voltage is tapped for one of the plates *V* of the cathode-ray tube which deflect the cathode ray in a vertical direction. Furthermore, at positions *1* and *3* of switch S_2 (cf. fig. 6) the synchronising signal *J* for the time-base unit (cf. fig. 4) is also drawn from *M*. To ensure that the potentials applied to the pair of plates *H* are symmetrical, the pentodes directly to the deflector plates *V* of the cathode-ray tube by cutting out the amplifier altogether by putting switch S_3 into position *3*. The maximum intensity of the signals which can be applied by using the amplifier across K_5 and K_7 is 45 volts, when a power of 0.2 watt is converted in the resistance R_6. If only the valves L_3 and L_4 are used for amplification, a standard image 6 cm in size is obtained with a voltage of 0.5 volt across

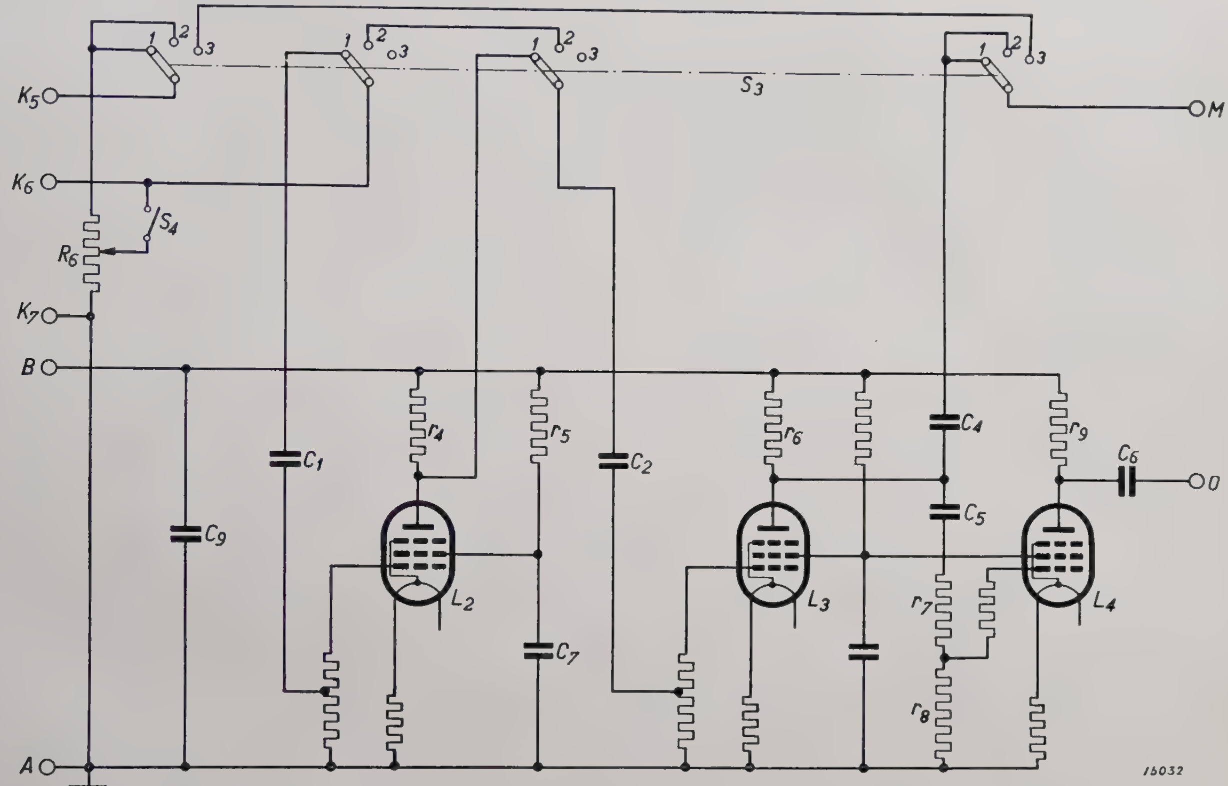

Fig. 7. Simplified circuit of the amplifier for the signal under investigation. A direct voltage of about 400 volts is applied across terminals *A* and *B*. The incoming signal is applied across K_5 and K_7 (or K_6 and K_7). By means of switch S_3 different types of amplification can be selected. The amplified or unamplified signal is then applied through terminals *M* and *O* to the plates *V* which impart a vertical deflection to the cathode ray (cf. fig. 1). For L_2 a pentode AF7 is used and for L_3 and L_4 pentodes AL4.

L_3 and L_4 are connected in such a way that the anode of L_4 gives through condenser C_6 a voltage form at the terminal *0* which is similar to that at terminal *M* but has an opposite sign. The ratio of the resistances r_7 and r_8 is so chosen that the anode alternating voltages of L_3 and L_4 have the same absolute value. The voltage at terminal *0* is then applied to the other pair of deflecting plates *V*.

If the signal to be represented by the oscillograph possesses a sufficient intensity, it can also be applied the terminals; when using the whole amplifier the same size of image may be obtained with signals of only 0.05 volt. As a 6-cm image is quite adequate, voltages from 5 millivolts upwards may be investigated. Care must be taken that at the deflector plates, both at *V* and at *H*, no voltages exceeding 90 volts are applied. The apparatus is suitable for frequencies from 10 to 500000 cycles; at the highest frequency the amplification ratio has not yet dropped 10 per cent.

Compiled by G. P. ITTMANN.

OPTICAL TELEPHONY

By J. W. L. KÖHLER

Summary. In the apparatus for optical telephony described in this article, a modulated ray of light is generated by feeding an incandescent lamp simultaneously with a direct current and with an alternating current from a microphone amplifier. The characteristics of this lamp are discussed. The range of transmission of this method is limited by the noise interference produced at the receiving apparatus. The means for suppressing this interference as far as possible are outlined. The apparatus described has a transmission range of 4.5 km when using white light and of 3 km with red light.

Introduction

The term optical telephony has been applied to the method of telephonic intercommunication by means of light rays, and is thus an extension of the principle of the ordinary signalling lamp by means of which telegraphic signals are transmitted. In the latter method an incandescent lamp fitted with a reflector is provided as a transmitter at each of the two points of intercommunication and by means of these a parallel beam of light is transmitted to the opposite receiving point. Each lamp is connected in circuit with a Morse key and, with the aid of the two beams of light employed, Morse signals can be transmitted and thus a channel of intercommunication established.

This system of telegraphic intercommunication occasions a considerable loss of time which in many cases has proved a serious obstacle to its use. This difficulty has been avoided in optical telephony, where the intensity of a beam of light is also varied periodically, not by Morse signals but by the speech frequencies which are used for intensity modulation. Reception is therefore not possible with the naked eye as with Morse signals, but requires the use of a photo-sensitive cell with an amplifier and telephone.

The complete equipment for optical telephony comprises the following components (see *fig. 1*). At the transmitting station there are provided a lamp L which is fed with direct current and is located at the focus of the reflector R, as well as a microphone M and an amplifier V_Z which amplifies the microphone current for modulating the beam of light. With this arrangement an image of the incandescent lamp filament is obtained at a great distance. The size b of this image is determined by the distance a between transmitter and receiver, the focal length f of the mirror and the size v of the filament, according to the expression:

$$b = \frac{v \cdot a}{f}$$

If, for instance, $a = 1$ km, $v = 0.1$ mm and $f = 75$ mm, then $b = 130$ cm. If this image is thrown on a parabolic reflector R' a portion of the image

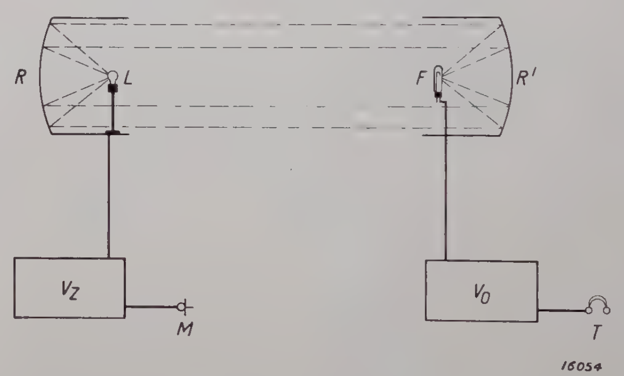

Fig. 1. Diagrammatic sketch of intercommunication by optical telephony. R and R' are the transmitting and receiving mirrors. L is the incandescent lamp. The lamp is modulated by the microphone M and the transmitter amplifier V_Z. At the focus of the receiving mirror the photo-electric cell F is situated which converts the light fluctuations into alternating currents: after amplification by the receiving amplifier V_O these alternating currents become audible in the telephone T.

can be directed on to the photo-electric cell F situated at the focus. The receiving end is also equipped with a photo-electric amplifier V_0 and a telephone T.

Transmitter

Simple consideration of the various methods by which the intensity of a beam of light can be modulated with speech frequencies indicates that several of these methods cannot be employed in the present case, since with them the position of the

image varies. Thus, for example (see *fig. 2*) an image of the lamp filament can be obtained by means of a supplementary lens L_1 and the image periodically covered with a screen S which is

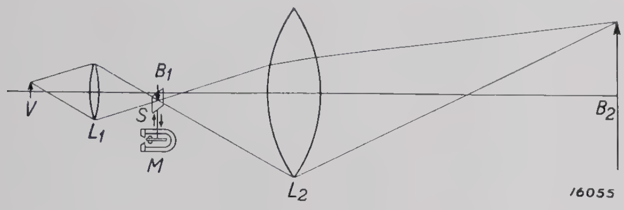

Fig. 2. Modulation of light with a screen. V is the source of light of which the lens L_1 produces the image B_1. This image is situated at the focus of the lens L_2, which throws an image B_2 to infinity. At the position of B_1 the screen S is placed which is moved up and down by the electromagnetic system. In this way the image B_2 is covered to varying degrees.

controlled by an electro-magnetic system M. The total flux of the beam will then certainly vary, but at the receiving mirror, where an image of the filament is reproduced, it is not the intensity of the image that will vary but merely the size of the image; part of the image will in fact be covered. This method can thus only be employed where the image is small compared with the receiving apparatus, while in practice the very reverse is actually the case. It is therefore essential for the image to be maintained as a whole at the receiving station, but to have a fluctuating intensity. This may be achieved in various ways, viz:

1. The beam of light is screened off by a screen placed in the immediate vicinity of the lens.
2. The beam of light is passed through a medium with a variable transmissibility.
3. The temperature of the incandescent filament is varied.

The first method requires only brief consideration. Since the transmitting mirror always has a fairly large diameter (e.g. about 20 cm), it is evident that the diaphragm or screen must be of the same size. But it is very difficult to vary the size of a diaphragm of these dimensions with a frequency of 2000 cycles per second.

An example of the second method is the Kerr cell (*fig. 3*). This cell is a condenser K with a liquid dielectric which has the property of being double-refracting in an electric field. The two light components, whose electric fields vibrate parallel and perpendicular to the field, are propagated with different velocities in the double-refracting medium. This phenomenon is utilised in the following way for modulating the light radiated. The light from the incandescent lamp becomes polarised linearly by the nicol N_1, which is so arranged that it only allows light to pass through whose plane of vibration makes an angle of 45° with the direction of the electric field in the plane perpendicular to the direction of propagation. This direction is indicated

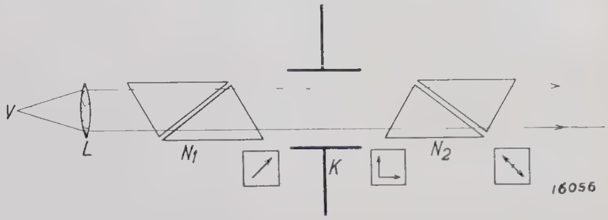

Fig. 3. Light modulation with the Kerr cell. The light from the light-source V is rendered parallel by the lens L. The beam of light then passes through the nicol N_1 by which it is linearly polarised (the arrow marked below denotes the direction of polarisation in the plane perpendicular to the direction of propagation). When the light has then passed through the double refracting medium of the Kerr cell, the phases of the vertical and horizontal components are displaced with respect to each other. The second nicol N_2 is crossed with respect to the first. If no potential is applied to the plates of the Kerr cell, the two transmitted components will just balance each other beyond N_2. Owing to the displacement in phase sustained by the components in the double refracting medium light will, however, pass through N_2.

by the arrow in the plane sketched below the figure. In the electric field of the Kerr cell K the equal vertical and horizontal field components of this vibration are propagated at different velocities. The two components then pass through the nicol N_2, which is so arranged that it only allows light to pass whose electric field vibrates in a direction perpendicular to the direction of transmission of N_1. Of the light waves with electric vectors vibrating in vertical and horizontal planes which issue from the Kerr cell, only those components pass through the second nicol which vibrate in the plane of transmission of N_2. This is also shown by arrows in fig. 3. If no potential difference is applied to the condenser of the Kerr cell, then, as may readily be seen from the figure, these two equal and opposite components just balance each other. In these circumstances, as is well known, no light passes through the crossed nicols N_1 and N_2. But if a potential is applied to the Kerr cell, then the two components which pass through N_2 suffer a phase displacement owing to the difference in their velocities of propagation in the double-refracting medium. They are in this case no longer equal and opposite at every instant and thus do not balance each other, so that light passes through with the same periodicity as the frequency of the potential applied to the Kerr cell. An advantage of this method is the complete absence of inertia, although on the other hand the nicols and the rest of the system absorb a considerable amount of light and thus make the method uneconomical.

A third method which starts with an incandescent lamp fed with direct current, has been evolved at the Philips Laboratory. This direct current has superposed on it the alternating current furnished by the microphone amplifier (*fig. 4*), so that the temperature of the hot filament varies with the

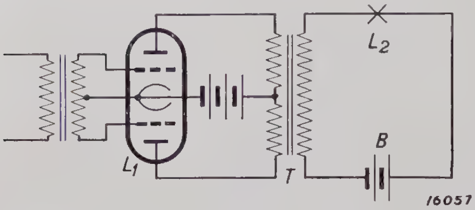

Fig. 4. Modulation of the incandescent lamp. The lamp N_2 is fed from the battery B. This circuit contains the secondary winding of the output transformer T of the transmitting amplifier. L_1 is the power valve of the amplifier, viz, Philips KDD 1 valve.

frequency of the alternating current. To visualise this, consider the energy fed to the filament by the direct and alternating currents. If a is the amplitude of the direct current, b that of the alternating current (peak value), r the resistance of the filament regarded as independent of the temperature, ω the frequency of the alternating current and w the power input, we have:

$$w = r\,(a + b \sin \omega t)^2 = r\,a^2\,(1 + m \sin \omega t)^2 \quad . \quad (1)$$

where $b/a = m$ is the degree of modulation. We thus get:

$$w = r\,(a^2 + 2\,ab \sin \omega t + {}^1/_2\,b^2 - {}^1/_2\,b^2 \cos 2\omega t) =$$
$$= r\,a^2\,(1 + 2\,m \sin \omega t + \frac{m^2}{2} - \frac{m^2}{2} \cos 2\omega t) \quad . \quad . \quad (2)$$

This expression contains a constant part and a variable part. The first term of the alternating energy, which is the determining factor, is $2ra^2m \sin \omega t$, and this has the same frequency as the alternating current; the second term has double this frequency. Naturally this second term is undesirable. On complete modulation, i.e. $m = 1$, its energy is $^1/_4$ of that of the fundamental wave. The potential difference at the photo-electric cell is proportional to the light energy and so in this case has a distortion of 25 per cent.

The result desired is that the intensity of the light shall vary with the fundamental frequency. Since small temperature fluctuations at the filament cause variations in the luminous intensity which to a first approximation are proportional to the temperature fluctuations, the temperature must fluctuate with the fundamental frequency. With a definite rate of a.c. input per second the magnitude of these temperature fluctuations is determined mainly by the thermal capacity of the filament and by the frequency.

Simple calculation shows how the energy input should be regulated in order to obtain a temperature

$$T = T_o + A \sin \omega t \quad . \quad . \quad . \quad . \quad (3)$$

which fluctuates sinusoidally with the time t. The energy input ($E\,dt$) per element of time dt is dissipated partly by radiation ($W\,dt$), whilst the remainder ($C\,dt$) is imparted to the filament, whose thermal capacity is C, to produce a temperature rise dT:

$$E\,dt - W dt = C\,dT \quad . \quad . \quad . \quad . \quad (4)$$

The energy W dissipated per unit of time can be approximately represented by:

$$W = W_o + a\,(T - T_o) \quad . \quad . \quad . \quad (5)$$

where W_0 is the mean energy dissipation in unit time. Hence the energy input (E) per unit of time required at each instant is given by:

$$E = W_o + a\,A \sin \omega t + C\,A\,\omega \cos \omega t \quad . \quad (6)$$

If the frequency ω is sufficiently high, the last term in equation (6) will have the largest value, so that the expression for the input energy required $E - W_0$ may be approximated as follows:

$$E - W_o = C\,A\,\omega \cos \omega t \quad . \quad . \quad . \quad (7)$$

The following conclusions may be drawn from this expression:

1. If a specific a.c. power is fed to a given filament in each second, the product $A\,\omega$ is determined. The amplitude A of the temperature fluctuations will then be inversely proportional to the frequency ω.
2. But if we have filaments of different diameters and employ a constant frequency, the constant energy which must be supplied to the filaments to maintain them at a specific temperature will be proportional to the diameter d of the filament. This energy is radiated by the surface of the filament, and will therefore be proportional to the surface area, and hence proportional to the filament diameter. Now if the input energy is made to vary with a definite modulation coefficient, then the a.c. power according to equation (2) will be proportional to the constant energy component and hence also proportional to the diameter of the filament. We thus find that in equation (7) the a.c. power $E - W_0$ is proportional to the diameter d of the filament, whilst the thermal capacity C of the filament is naturally proportional to its volume, i. e. to d^2. It thus follows that the amplitude A of the temperature fluctuations is inversely proportional to the diameter d of the filament.

Measurements have confirmed this conclusion, at least for frequencies at not too low a level. But the amplitude of the temperature variations is very small in the case of a lamp with a filament burning in vacuo.

In this respect gas-filled lamps are more suitable than vacuum lamps for the following reasons. Equation (6) also applies to gas-filled lamps, but W_0 and a are then much greater in value. If the frequency is made sufficiently high, equation (6) can again be reduced to the form of expression in (7). The presence of the gas-filling has therefore not altered the relationship between temperature variation and the a.c. power input. The amplitude of the temperature fluctuations is thus independent of the gas filling when the a.c. input, filament diameter and frequency are constant. But, owing to the much greater thermal conductivity of the gas, a much greater stationary power is now required to maintain the filament at a definite temperature than in the absence of the filling. At the same degree of modulation m, the possible alternating power is thereby also increased in the same ratio, and in accordance with equation (7) also the amplitude of the temperature variations. For example, the temperature fluctuations of the filament are three times greater with a nitrogen filling, and even ten times greater with hydrogen, than in vacuo.

A high temperature is desirable because the variation produced in the amount of light radiated by a specific temperature change is greater at a higher mean temperature. But there is a limit in this direction as the life of the lamp becomes rapidly shortened with increase in the temperature.

Receiver

The arrangements at the receiving terminal follow directly from the above considerations. The photo-electric cell converts the intensity fluctuations of the light into alternating currents which are amplified and passed to the telephone (*fig. 5*). But the intensity of the beam of light decreases with the square of the distance, and still more so as a result of absorption and dispersion in the atmosphere. Thus, in order to obtain a sufficient intensity at the telephone a high amplification must be employed, which determines the practicable range of transmission with this apparatus. It is well known that the amplification cannot be infinitely increased, as noise interference in the amplifier becomes heavily intensified at the same time. The sources of these noises may be classified into three groups as follows:

1. The first amplifying valve;
2. The coupling resistance coupling the photo-electric cell with the amplifier, and
3. The photo-electric cell itself.

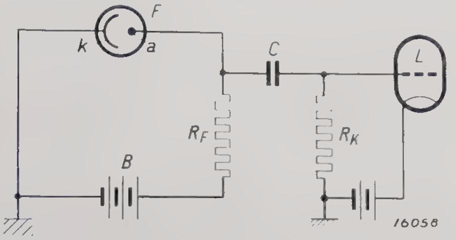

Fig. 5. Connection of photo-electric cell with receiving amplifier. The battery B furnishes the voltage for the photo-electric cell F. The alternating currents, which are produced by variable illumination of the cell, generate an alternating voltage at the resistance R_F. This voltage is passed through the condenser C and the resistance R_K to the grid of the input valve L of the amplifier.

Space does not permit of a detailed discussion of the interference due to the amplifier, although a few of the more important points may be dealt with.

Noises due to the Amplifying Valves

These interfering noises are due to the electric current, here the anode current, not being a continuous current, but a stream of electrons which are detached from the cathode in a haphazard fashion. These small current fluctuations produce a noise in the telephone. There is thus a natural limit set to reception, for if the amplitude of the variation in anode current produced by the signal is smaller than the current variation due to the inherent noises the signal will no longer be detectable. The only remedy here is to use a valve which gives a minimum of noise and to adjust it as accurately as possible.

Noises due to the Grid-Circuit Resistances

Owing to the Brownian movement of the electrons in the resistance slight voltage fluctuations are produced in it which cannot be eliminated in any way. But the various ratings can be so adjusted that interference is reduced to a minimum. The amplitude of the noise voltage at the resistance is proportional to the root of the resistance rating. At a specific illumination the photo-electric cell gives a definite current. The voltage-drop produced at the coupling resistance by this current is proportional to the resistance. Hence if we double this resistance, the signal voltage at this unit will also be doubled, whilst the noise voltage will be $\sqrt{2}$ times greater. We have thus reduced the ratio

of signal voltage to noise voltage by $\sqrt{2}$. Although a greater resistance increases the noise, a higher coupling resistance is nevertheless of advantage here. On the other hand this resistance must not be made too large, owing to the input capacity of the valves connected in parallel to it, the capacities of the photo-electric cell and the leads which for high frequencies short the resistance.

Noises in the Photo-electric Cell

This noise is due to the same radical cause as the noise produced in the amplifying valves. In addition to the beam of light directed on to the photo-electric cell, the latter is also exposed to daylight, which generates a direct-current component in the photo-electric current. This component, similar to the anode current, is also subject to fluctuations owing to electronic conditions, such variations being responsible for the noises. In addition the illumination itself can also fluctuate and constitute a new source of disturbance. The only remedy here is to screen off daylight as far as possible. At the focus of the receiving mirror an image of the transmitting lamp and its surroundings is produced. If a screen is therefore set up with the same size as the image produced by the receiving mirror from the transmitting mirror, daylight will practically be completely cut off (*fig. 6*). But this is only the case with an ideal mirror. With ordinary

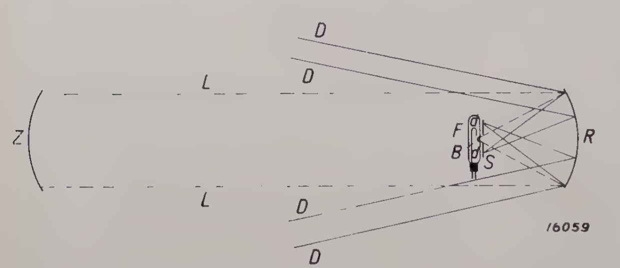

Fig. 6. Screening off daylight. At the focus of the receiving mirror R the image B of the incandescent lamp is produced which is set up at the focus of the mirror Z. Daylight rays (D) from the vicinity of the transmitting lamp are focussed at the points d. The screen S prevents access of these rays to the photo-electric cell F.

mirrors with a short focus parallel beams of light are not focussed to a mathematical point but to a spot about 1 mm in diameter. If we therefore make the aperture of the diaphragm or screen less than 1 mm, more daylight will be cut out but at the same time also a part of the useful light from the transmitter, so that no advantage will be gained. A much better method is to increase the focal length, whilst lenses can be used to advantage instead of mirrors. With ordinary lenses the focus is still 1 mm in size, although now, owing to the greater focal length, the image of the transmitting mirror is also larger, so that only a smaller part of the surroundings is visible through the diaphragm aperture of 1 mm.

In this way very good results have been achieved with a lens of 40 cm focal length. It is evident that with the smaller diaphragm aperture it is more difficult to direct the receiver on to the transmitter, yet with the dimensions selected this difficulty has remained within reasonable limits.

There is also a general method which may be employed for suppressing interfering noises. These noises cover a frequency band, and the aggregate noise voltage increases with the square root of the width of the frequency band in question. If provision is made that the amplifier does not amplify those frequencies which are not absolutely essential for telephonic communication, the noise may be considerably reduced. The receiver has therefore been designed on such lines that frequencies above 2500 cycles are not amplified.

General Remarks

It has already been indicated that owing to the thermal capacity of the hot filament the amplitude of the luminous fluctuations decreases considerably with rising frequency. To ensure intelligible intercommunication it is naturally necessary for the frequency characteristics from the microphone to the telephone to be as near horizontal as possible for speech frequencies between 300 and 2500 cycles. For this reason a suitable correction must be made. The most practicable method for doing this appears to be to give the transmitter a characteristic which rises with the frequency, for if this means is employed in the receiving amplifier, interfering noise would become intensified. As long as the current through the lamp is only weakly modulated, no difficulties are encountered in this direction. With a constant input power for all frequencies at the transmitting amplifier the degree of modulation of the current through the lamp will, however, be greater for the higher frequencies than for the lower ones; this will not constitute a disadvantage as long as the degree of modulation for the higher frequencies does not attain 100 per cent. Upon further increase in the input voltage the current at the highest frequencies will at a given instant be fully modulated, so that amplification may not be further increased. But the current is then by no means fully modulated in the lower frequencies, so that the transmitter is apparently being run at a very low efficiency. In practice, however, entirely different conditions prevail since the human voice contains a far lower

proportion of the higher frequencies than of the lower ones. When speaking into the microphone the current through the incandescent lamp is almost equally modulated by the different frequencies, provided the transmitting amplifier is given such a characteristic that, with an input signal having an intensity independent of frequency, the amplitude of the temperature fluctuations is similarly independent of frequency.

Since an apparatus for optical telephony must be readily portable, it is desirable for all amplifiers to be fed with current from anode batteries. The output power of the amplifier is therefore limited. Now with a specific modulation the a.c. energy absorbed by the lamp is proportional to the direct-current energy. The latter must therefore be kept low, which may be arrived at by making the filament short. From these considerations a lamp has been evolved which requires a 3-watt direct-current supply in order to burn at the correct temperature. At full modulation $1^1/_2$ watts is therefore sufficient. This energy can be controlled by the Philips KDD 1 valve, a double triode, the lamps of which are used in the neighbourhood of the zero of the characteristic (*B*-connection). This arrangement has the advantage that the anode battery does not have to furnish a current in the absence of modulation. The use of a small filament is furthermore useful since it gives a very narrow beam of light; the dispersion with a focal length of 75 mm is only about $1^1/_2$ per cent of the range of transmission.

Practical Results.

The efficiency and reliability of intercommunication depend inter alia on the wave-length of the light used, since the photo-electric cell has a different sensitivity for different wave-lengths, whilst moreover atmospheric absorption may also vary for different wave-lengths. Standard caesium photo-electric cells have a maximum sensitivity in the infra-red region of the spectrum, but also respond to visible light. Red light is less dispersed by air than violet light; nevertheless the intensity still decreases considerably if, in place of white light, dark red or even infra-red light is used by introducing a filter. The range of transmission is then reduced by at least 30 per cent.

With the apparatus built in the laboratory, satisfactory inter-communication was maintained over a distance of 4.5 km with white light and over 3 km with red light. The transmitting and receiving mirrors were each 130 mm in diameter. It should be mentioned in this connection that the range of transmission is proportional to the diameter of each of the reflectors. The data given here apply for good visibility, but it is quite possible to maintain intercommunication over a medium distance also through fog when once established, although to set up the required channel of communication is very difficult under these circumstances.

Compared with other methods of intercommunication, optical telephony has the disadvantages of being dependent on atmospheric conditions and of offering only a restricted range of transmission. On the other hand it has certain advantages; thus, compared with signalling lamps, messages can be transmitted with much greater speed, which applies in fact as regards all methods of telegraphic transmission. In regard to short-wave spark telegraphy there is, moreover, the added advantage of secrecy. Owing to the extremely small dispersion of the ray it is impossible to detect the position of the transmitter during the day, even when using white light; messages therefore cannot be tapped. For the same reasons intercommunication is also proof against malicious interference.

PRACTICAL APPLICATIONS OF X-RAYS FOR THE EXAMINATION OF MATERIALS

IV.

By W. G. BURGERS.

Perhaps the most fruitful application of X-rays for practical purposes is in those cases where the presence of certain compounds has to be established in a mixture or a chemical reaction product, or a chemical product has to be identified. Every crystalline body possesses its own characteristic crystal structure and hence gives a specific X-ray pattern. A given mixture can therefore in most instances be analysed directly by comparing its X-ray photograph with the patterns obtained for those compounds whose presence is suspected in the product under examination. Naturally, for the application of this method it is essential to have at hand a series of standard X-ray photographs relating to the comparison substances in question. These radiographic standards can usually be obtained without difficulty.

To enable the detection of an impurity or admixture in a given substance by means of X-rays, the impurity must generally be present in at least a certain percentage in order that the diffraction pattern given by it can be recognised besides that of the principal constituent. In this respect the X-ray method is subject to a certain limitation [1]) as compared with chemical analysis. Nevertheless, chemical analysis is only able to identify the nature of the atoms (or the ions) present, whilst the X-ray method directly indicates the compounds present; thus, by means of X-rays it is possible to distinguish for instance between a mixture of NaCl + KBr and another containing KCl + NaBr (see example No. 7). It is evident that the two methods of analysis supplement each other to a marked degree, since they afford information on different matters.

In view of the multiplicity of these special applications of the radiographic examination of structure (i.e. for identification), practical examples of this kind will frequently be encountered.

[1]) In the case where mixed crystals or solid solutions are formed by which the crystal lattice is altered, the presence of admixtures can often be indirectly detected even in much smaller quantities.

6. Diagnosis of Renal Calculus

For the successful treatment of patients suffering from renal calculus it is, inter alia, essential to know whether the calculi consist of oxalate or phosphate. In general this can be easily established by chemical means. But in many cases (where the calculi are small) it may be desirable not to sacrifice any part of the stone for chemical analysis, and just in these instances a radiograph will prove of great value. *Fig. 1a* shows an X-ray diffraction pattern which was obtained from a small quantity of a powdered calculus, whilst *fig. 1b* reproduces an X-ray diffraction pattern of calcium oxalate. From the identity of the arrangement of the various lines in the two radiographs it may be concluded that the calculus under examination was composed largely of calcium oxalate.

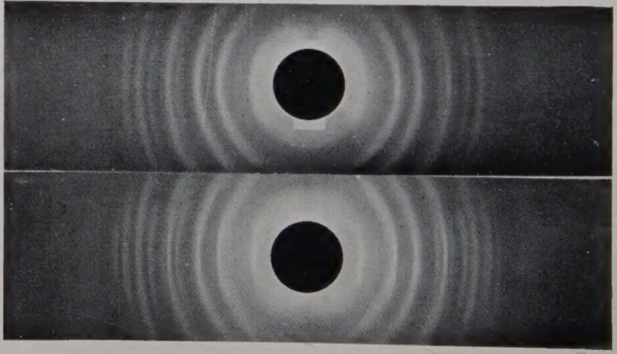

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Fig. 1. Diagnosis of renal calculus.
a) Powder of a renal calculus
b) Calcium oxalate

7. Detection of Compounds in a Mixture

By pounding the powdered substances in a mortar, mixtures were produced of (a) NaCl + K Br, and (b) KCl + NaBr, equivalent molecular quantities being taken of each substance.

Figs. 2a and *b* reproduce the radiographs of the two mixtures side by side, and the difference between them may be clearly seen. From *figs. 3a-c*

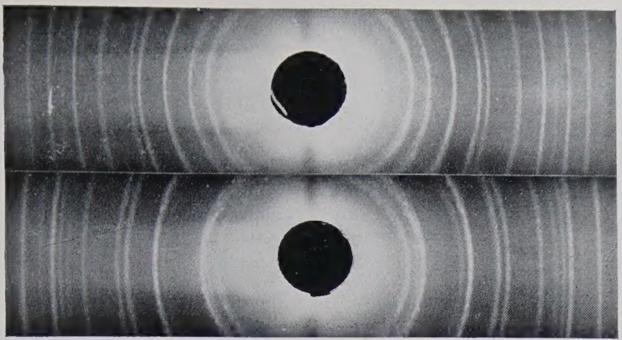

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Fig. 2. Mixture of chemical compounds.
a) NaCl + KBr
b) KCl + NaBr

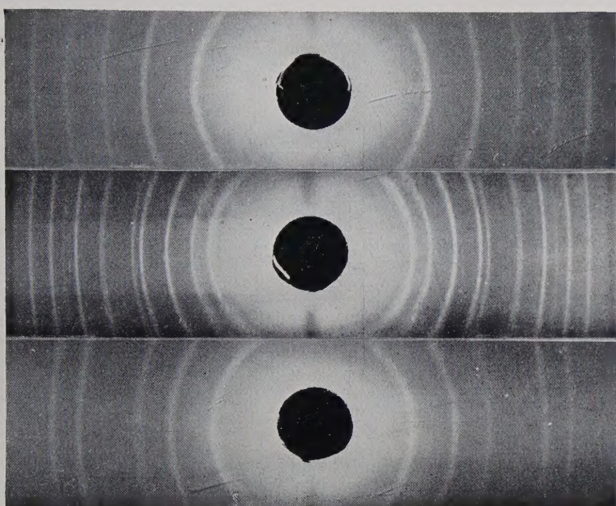

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Fig. 3. Identification of compounds in the mixture in fig. 2a.
a) NaCl
b) NaCl + KBr (= fig. 2a)
c) KBr

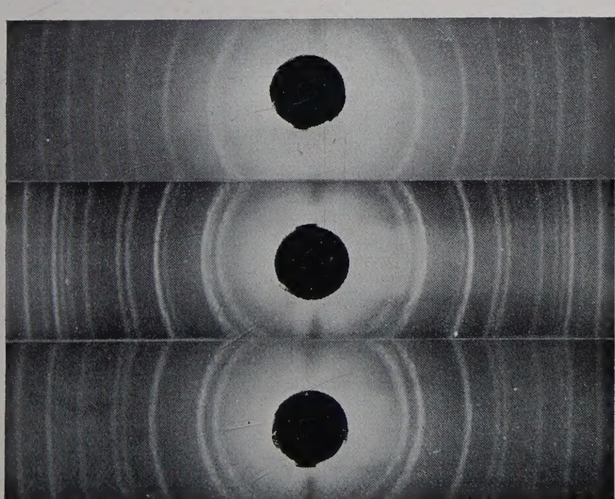

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Fig. 4. Identification of compounds in the mixture in fig. 2b.
a) KCl
b) KCl + NaBr (= fig. 2b)
c) NaBr

and *4a-c*, which reproduce not only the radiographs of the mixtures but also those of the constituents, the composition of the mixtures may be deduced.

Ordinary chemical analysis would have shown the same atomic (or ionic) composition for both mixtures (2) and would thus have given no information as to which metal was present as chloride and which as bromide.

8. Identification of Aluminium Oxide

Aluminium oxide is employed in the manufacture of incandescent lamps. There are various modifications of it, including the corundum modification, which occurs in natural crystals. This modification is formed for instance by heating aluminium hydroxide to a very high temperature, in the neighbourhood of 1200 deg. C. For the technical product used in manufacture it was essential to know whether this corundum modification was actually present, as otherwise heating to a very high temperature might have caused a conversion undesirable for various reasons. This point is very difficult to establish by chemical means, but a comparison of radiographs of the powder, which the works had submitted for examination (*fig. 5a*), and of pulverised natural corundum (*fig. 5b*) showed

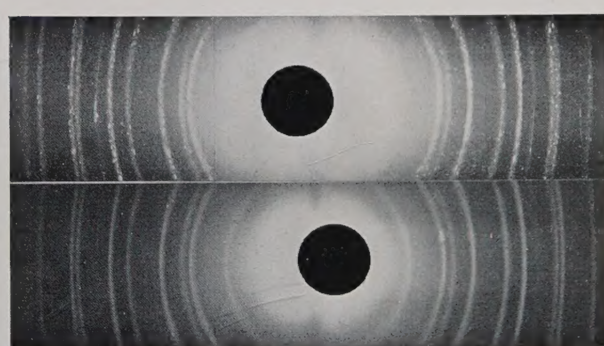

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Fig. 5. Identification of a modification of aluminium oxide as corundum.
a) Aluminium oxide (initially of unknown modification)
b) Pulverised natural corundum

that both substances had the same arrangement of lines. It follows from this that at least 90 per cent of the aluminium oxide is present as the corundum modification. From the presence of individual dots on the lines in fig. 5a (see the second article in this section, in No. 2 of this Review, p. 60) it may be furthermore concluded that the crystals of aluminium oxide in the technical product are at least in part greater than 10 μ.

[2]) The above example is not of a practical nature, but has been included here merely to bring out the fundamental difference between the potentialities of X-ray and chemical analysis.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

No. 1059: M. J. O. Strutt and A. van der Ziel: Messungen der charakteristischen Eigenschaften von Hochfrequenz-Empfangsröhren (Elektr. Nachr.-Techn. **12,** 347-354, Nov. 1935).

For a variety of commercial and other high-frequency penthode valves the authors have measured the input and output impedances, the slope and the reaction of the anode on the grid in the short-wave range. In this range the damping at the input and output is inversely proportional to the square of the frequencies. Up to a frequency of approximately 60 megacycles, the slope is still roughly equal to its statical value. The reaction of the anode on the grid can be represented by a capacity which with long waves roughly agrees with its static value. On shortening the wavelength the reaction diminishes and many in fact change its sign. At very high frequencies its absolute value increases in proportion to the square of the frequency. It appears that the pentodes (type AF 3) investigated are quite suitable for high-frequency amplification up to wavelengths op 7m as used for television purposes.

No. 1060: J. van Niekerk: Evaluation of the relative toxic effects of large doses of Calciferol and the crystalline antirachitic preparation substance L (Arch. néerl. de physiologie de l'homme et des animaux **20,** 559-561, Dec. 1935).

It was found that the ratio of the toxic to the antirachitic dose with Reerink and van Wijk's preparation is almost the same as with Calciferol. For the smallest toxic dose the author has obtained roughly the same value as other investigators.

No. 1061*): M. J. Druyvesteyn: Der positive Ionenstrom zur Glühkathode einer Gasentladung (Phys. Z. Sowjetunion **8,** 579-581, Nov. 1935).

Various investigators have measured the positive ionic current in discharges through gases with a cold probe-electrode. They have also determined the electronic emission of the heated probe-electrode, which is raised e.g. to a potential about 7 volts lower than the surrounding plasma. If it was then found that the discharge was not affected by electronic radiation at a certain distance from the cathode, some investigators assumed that the ionic current flowing towards a heated cathode was the same as that to a cold one. The author points out that this assumtion is untenable and from measurements made by Gvosdover concludes that the ionic current flowing to a heater electrode is roughly double that flowing to a cold one. For the ratio between the electronic and ionic currents using a hot cathode the author obtains the value 200, which is in better accord with the plasma theory of Langmuir than the value of 400 which Gvosdover deduces himself from his measurements.

*) A sufficient number of reprints for purposes of distribution is not available of those articles marked with an asterisk (*). Reprints of other papers may be obtained on application from Philips Laboratory, Kastanjelaan, Eindhoven, Holland.

No. 1062: K. F. Niessen: A contribution to the symbolic calculus (Phil. Mag. **20,** 977-997, Suppl. Nov. 1935).

New methods are given for deriving from a function and its operational transformation certain new functions which are inter-related as "original" and "operational image". For certain "images" of simple form this method enables the original to be deduced. The new operational relationships finally give new mathematical relationships.

No. 1063: J. M. A. van Liempt: Eine Beziehung zwischen Umwandlungswärme und Umwandlungspunkt bei enantiotropen Modifikationen (Rec. Trav. chim. Pays-Bas **54,** 934-936, Dec. 1935).

On the basis of the equality of the sublimation velocities of two enantiotropic modifications at the transition temperature, a formula is deduced for the relationship between the heat of transformation and the transition temperature. This formula was tested for tin and suphur. Sufficient data regarding the specific heats of these elements as a function of the temperature are, however, lacking and preclude a thorough test of the formulae derived. It appears, however, that values of the correct order of magnitude are obtained on calculation of the above relationship.